Usability of an Adaptive Computer Assistant that Improves Self-care and Health Literacy of Older Adults

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Summary
Objectives: We developed an adaptive computer assistant for the supervision of diabetics' self-care, to support limiting illness and need for acute treatment, and improve health literacy. This assistant monitors self-care activities logged in the patient's electronic diary. Accordingly, it provides context-aware feedback. The objective was to evaluate whether older adults in general can make use of the computer assistant and to compare an adaptive computer assistant with a fixed one, concerning its usability and contribution to health literacy.
Methods: We conducted a laboratory experiment in the Georgia Tech Aware Home wherein 28 older adults participated in a usability evaluation of the computer assistant, while engaged in scenarios reflecting normal and health-critical situations. We evaluated the assistant on effectiveness, efficiency, satisfaction, and educational value. Finally, we studied the moderating effects of the subjects' personal characteristics.
Results: Logging self-care tasks and receiving feedback from the computer assistant enhanced the subjects' knowledge of diabetes. The adaptive assistant was more effective in dealing with normal and health-critical situations, and, generally, it led to more time efficiency. Subjects' personal characteristics had substantial effects on the effectiveness and efficiency of the two computer assistants.
Conclusions: Older adults were able to use the adaptive computer assistant. In addition, it had a positive effect on the development of health literacy. The assistant has the potential to support older diabetics' self care while maintaining quality of life.

Keywords
Adaptive computer assistance, self-care, older adults, diabetes, usability evaluation, smart homes

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1. Introduction

Lydia (aged 62) experiences increased thirst, frequent urination, fatigue, and blurred vision. Her physician diagnoses her with diabetes type II and prescribes a treatment. It includes performing a number of tasks, such as dietary and physical activities, monitoring her blood glucose, and taking medication. A key issue for Lydia is combining self-care tasks and her daily tasks, while maintaining a high quality of life.

Like Lydia, there is a growing number of diabetics. Approximately 21 million people suffer from diabetes type II in the U.S. alone [1]. This is presumably caused by the aging of the population and the growing number of people with obesity. This may lead to problems for the health care service to adequately meet health care demands.

Diabetics can potentially benefit from telecare. Remote care for people at home through information and communication technology (ICT) has multiple benefits, such as lowering costs, aging in place, and monitoring and assessing care needs [2]. Also, telecare can contribute to chronically ill patients' self-care [3]. Namely, assisting of activities, including enhancing health literacy [4], undertaken by individuals, families, and communities with the intention of preventing disease, limiting illness, and restoring health [5]. Adequate self-care, while maintaining quality of life, can help improve people's lifestyle and stimulate medical adherence [6].

Following the telecare concept, we designed a computer assistant for the supervision of diabetics' self-care. The assistant monitors the patient's electronic diary. Based on the collected data, the assistant supports self-care and mediates the communication between the patient and the (remote) medical specialists [7].

The computer assistant must enable self-care concerning limiting chronic illness and assisting in instances where acute treatment is required. In our design this was translated into two aspects. First, it enhances knowledge of diabetes and improves self-care by offering information on diabetes' background, cause, and treatment. Second, it diagnoses the health situation (e.g., hypo- or hyperglycemic attack) and suggests treatment.

Various studies proved the importance of ICT use in the health care service (e.g. [2, 8]). These studies discuss how ICT can be implemented in health care service and support medical specialists. However, there is little research on how this technology can support patients' self-care with the use of computer feedback [9, 10]. In previous studies [7, 11], we studied the influence of different computer assistant feedback styles on supervision of complex task environments. The assistant applied a cooperative feedback style (i.e., it has a coaching character, explains and educates the patient, and expects high participation of the user), or it applied a directive feedback style (i.e., it has an instructing character with brief reporting and expects low participation of the user). In summary, the cooperative style is oriented towards user satisfaction and long-term development. The directive style is oriented towards quick and efficient problem solving in cases of health anomalies (Table 1). Results showed that the cooperative assistant was more effective and satisfactory, where-

Table 1 Comparison of computer assistant dialog styles

	Cooperative dialog style	Directive dialog style
Assistant	Coaching	Directing
Characteristics	Educating Advising Oriented towards satisfaction Long-term development	Reporting Dictating Oriented towards quick problem solving
User demands	High participation level Committing	User is mostly uninformed Complying
Advantages	User learns new competencies Develops understanding Better performance in long-term User-assistant complementing	User needs few competencies Better performance in short-term Vigorous acting
Disadvantages	Assistant support can become tedious and patronizing	User is vulnerable to mistakes when called upon User loses idea of control

Table 2 Assistant types

Assistant type	Normal situation	Health-critical situation
Fixed	Cooperative feedback	Cooperative feedback
Adaptive	Cooperative feedback	Directive feedback

as the directive assistant was more efficient. Furthermore, personal characteristics, such as cognitive abilities and personality traits, proved to have a moderating effect on how people evaluated the assistant.

For limiting illness, the cooperative assistant was more preferable. However, if the patient is feeling unhealthy, the focus is more on acute treatment and restoring health. In this case, a directive assistant is more beneficial. To combine the advantages of both feedback styles, we propose an adaptive assistant that adapts its feedback to the patient's health situation (Table 2).

Due to its innovative character, implementation of telecare technology may be prone to misapprehension, errors and, eventually, abandonment [12]. This applies specifically to older users, who require more time to adopt technology, due to their decline of cognitive, physical and sensory functions (e.g. [13]). Therefore, it was critical that we evaluate the computer assistant on usability for this target user population.

In medical research on human subjects, consideration of the well being of the subject should take precedent over the interest of science. Even though we are empirically studying the use of a computer assistant and its benefit to the end user, we do not want to inordinately hinder them [14]. Consequently, we applied an incremental implementation approach and designed the assistant in phases [15].

Initially, we conducted domain, task and scenario analyses and interviewed diabetic specialists. In the current study, we evaluated an intelligent computer assistant with subjects who are not diabetics, but resemble the prospective users. Following this determination of feasibility and usability, the prototype will be developed and evaluated with diabetes type II patients in a field study.

Consequently, our main research question was whether an adaptive computer assistant facilitated supervision of older diabetics' self-care, concerning limiting illness, acute treatment, and developing health literacy. The first goal was to determine if the adaptive assistant was more usable than a fixed assistant, which does not adjust its feedback style to the patient's situation. Second, we investigated whether the assistant style influenced health literacy. Finally, we assessed whether personal characteristics had a moderating effect on how people evaluated the assistant.

We formed our initial expectations with the assumption that the use of health technologies promised to significantly improve the quality of self-care [2, 8]. In addition, given that the adaptive computer assistant's feedback style is designed for the patient's health situation, the adaptive assistant might lead to a higher level of usability [16]. Because the fixed assistant will continuously keep coaching, advising and educating the subjects, it might lead to a higher level of diabetes knowledge. Lastly, people have different personal characteristics which may influence the way the subjects would evaluate the assistant [17].

To validate our hypotheses, we conducted a laboratory experiment in the Georgia Tech AwareHome (www.awarehome.gatech.edu). A benefit of this type of smart home laboratory is the opportunity to facilitate natural behavior. This environment can enable potential users to consider the technologies in context and in return provide richer input [18].

2. Methods

Subjects were an ethnically diverse sample of 28 older adults, 15 male and 13 female, 20 Caucasian and 8 African American, between the ages 61 and 75 (M = 67, SD = 2.76), without diabetes type II. They cleared a visual acuity test at the level of 20/40 for far and near vision. Subjects received $30 for their participation in this study which lasted three hours. The study protocol was approved by the Georgia Tech IRB.

The computer assistant interacts with the patient through a patient interface (Fig. 1). The interface consists of an electronic diabetes diary, an interaction frame and a traffic light. The user fills in the diary daily, concerning dietary and physical activities, medication and bodily symptoms, such as glucose level. The assistant monitors the diabetes diary, assesses the patients' glucose level and symptoms, and gives feedback according to a number of rules (Fig. 2). These rules originate from American Diabetes Association documentation [19] and were written in collaboration with diabetes experts from the Leiden University Medical Center (LUMC), the Netherlands.

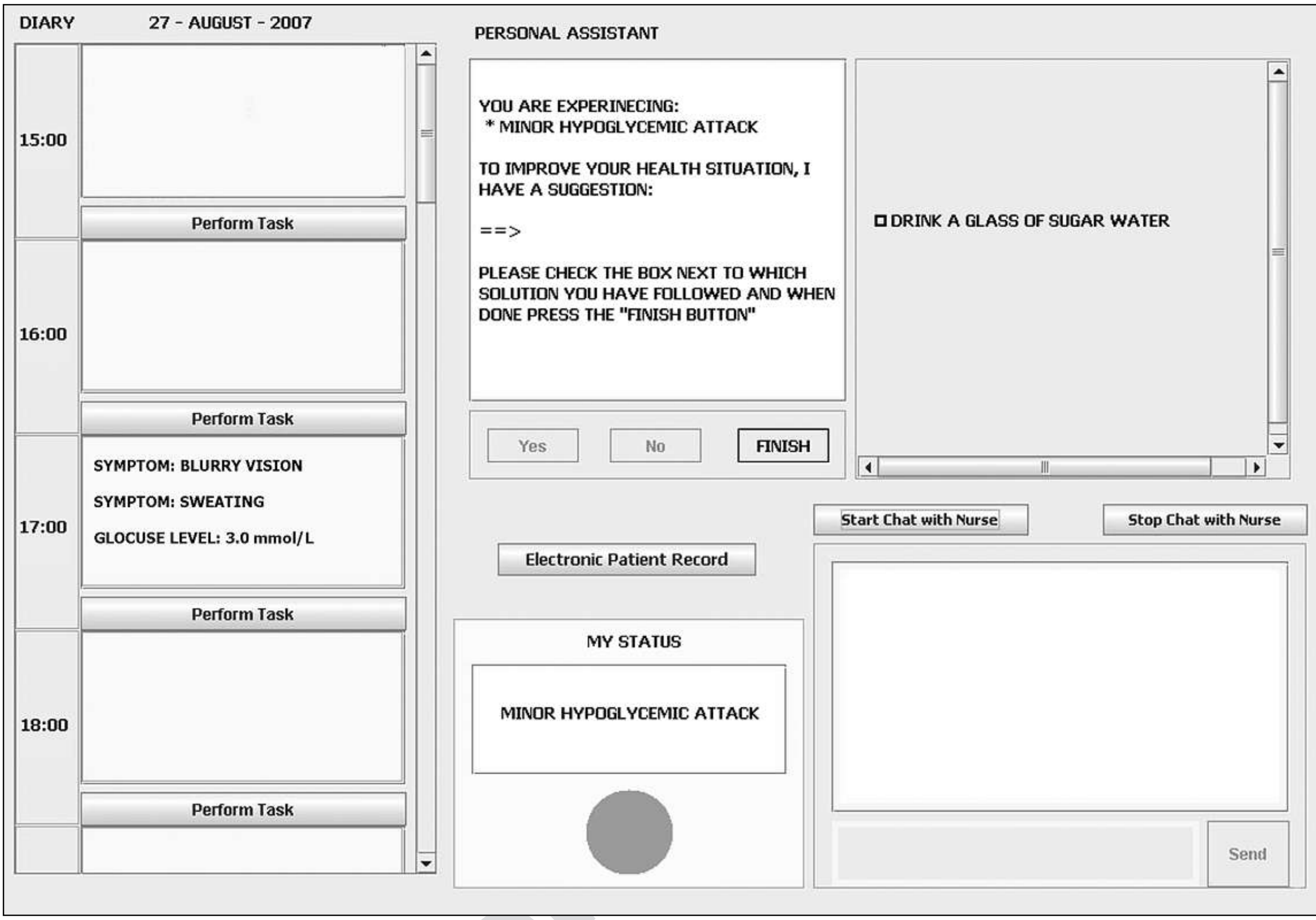

Fig. 1 Patient interface with electronic diary and computer assistant

To illustrate the function of the computer assistant, Figure 1 shows the patient has a glucose level of 3 mmol/L and experiences blurry vision and excessive sweating. The assistant diagnoses that the patient suffers from a minor hypoglycemic attack. It informs the patient of his or her current health situation and suggests a treatment, namely, to drink a glass of sugar water. Finally, it explains what the cause was of the critical situation and indicates how it can be prevented in the future. The behavior of the patient assistant is programmed as follows:

If 2 <glucose level <3 mmol/L and Symptoms = Blurry vision & Sweating
Then Health_Situation = Minor hypoglycemic attack
Suggestion = "Drink glass of sugar water."
Cause_and _Prevention = "Hypoglycemic attacks are caused by a low level of glucose in your blood. This can be prevented:
Mind your nutrition
Organize daily schedule to prevent stressful situations
Take glucose measurements frequently."

The traffic light represents the current health situation of the patient. A green light is shown when the patient is in a normal health situation. An orange light is shown when in a minor health-critical situation (glucose level between 3 and 4 mmol/L and between 8 and 10 mmol/L). A red light is shown when the patient has a severe health-critical situation (glucose level below 3 and above 10 mmol/L).

Subjects were tested on a number of cognitive abilities, including vocabulary [20], memory span, perceptual speed [21], and spatial ability. Also, we measured subjects' locus of control, which refers to two types of people: those with an internal locus of control (i.e., attribute events to their own control), and those with an external locus of control (i.e., attribute events to external circumstances) [22].

During the experiment, subjects performed tasks on the patient interface according to eight scenarios. Scenarios alternated from a normal to health-critical situation. The four health-critical scenarios described hypoglycemic and hyperglycemic attacks. We emphasized that in these scenarios the subject was not feeling well and it was imperative that the scenario be completed quickly. We used time pressure to in-

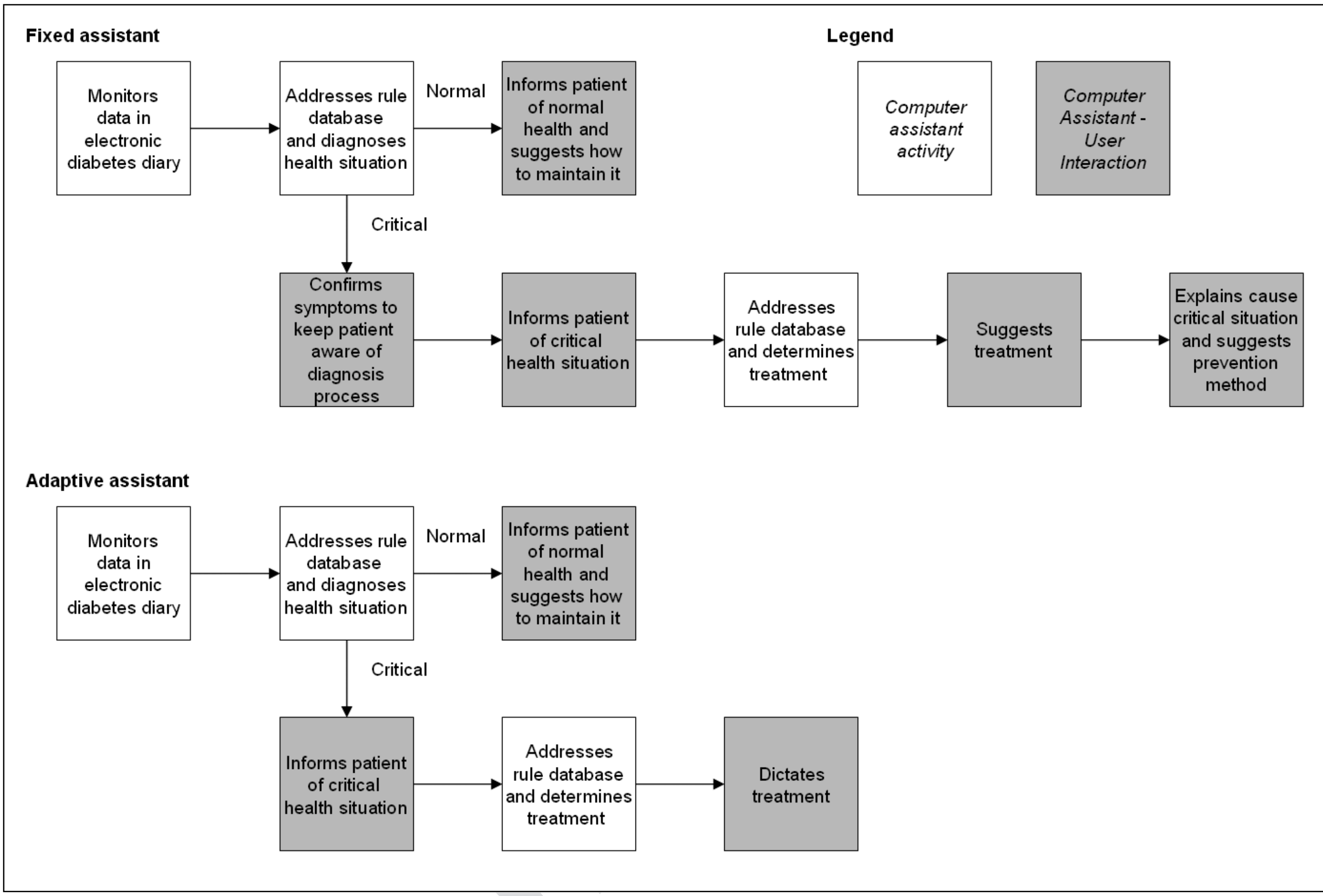

Fig. 2 Diagram of fixed and adaptive computer assistant behavior. Adaptive computer assistant does not involve the subject in the diagnosis process nor clarify how the critical situation was caused and how to prevent it in the future. Fixed assistant stays cooperative and does give this "educational" feedback.

crease the subjects' mental effort and stress with a timer facing the subject activated every 30 seconds with a beep. Subjects performed four scenarios with both computer assistant types. Half of the subjects in the group interacted during the first four scenarios with the fixed assistant and during the latter four scenarios with the adaptive assistant. The other half interacted with the converse.

We observed the influence of the computer assistant types on the experienced usability, concerning effectiveness, efficiency, and satisfaction. Effectiveness was measured by logging the errors made while completing the scenarios. Errors subjects made varied from entering the wrong tasks in the diary to incorrectly answering the assistant's questions. Efficiency was measured by logging the time required to fulfill the scenarios and mental effort experienced. Mental effort concerns the resources required to perform the task and was measured using the NASA-TLX [23]. Subjects were also asked to indicate which type of assistant (fixed or adaptive) they preferred. After four and, again, after eight scenarios, subjects completed a diabetes knowledge survey, containing eight multiple-choice questions dealing with aspects of type II diabetes. An exemplary question is "Type II diabetics' treatment generally consists of …". Finally, we studied the moderating effect of the tested cognitive abilities (memory span, vocabulary, perceptual speed, spatial ability) and personality traits (locus of control) on the evaluation of the assistant.

To validate our simulation of health-critical situations, we performed a paired-sample t-test comparing subjects' subjective rating of time pressure and mental demand during the scenarios. To evaluate the computer assistants' effectiveness, efficiency, and contribution of health literacy, we performed a repeated measures ANOVA with the factors of health situation (2 levels: normal and health-critical) and assistant type (2 levels: fixed and adaptive) on number of errors made, time, effort, and number of diabetes type II-related questions correct. To assess if subjects had a preference for the adaptive assistant, we performed a Chi-square test. To determine whether there was a relationship between personal characteristics and evaluation of the assistant's usability, we conducted multiple regression analyses on the subjects' performance data with seven predictors. The predictors were gender, age, vocabulary, perceptual speed, memory span, spatial ability, and locus of control.

3. Results

During the health-critical situations, experienced time pressure (t(27) = – 4.98, p <.001) and mental demand (t(27) = – 3.03, p = .005) were both significantly higher than during the normal health situations. We aimed at putting the subjects in a time-pressurized and stressful situation and these results validate that manipulation.

The effectiveness of the two computer assistants in relation to the health situation is shown in Figure 3. Subjects made more mistakes when experiencing a health-critical situation (*M* = .86, *SE* = .13) than when experiencing a normal situation (*M* = .16, *SE* = .007), F(1,27) = 36.06, p <.001. However, subjects interacting with an adaptive assistant made significantly fewer errors (*M* = .54, *SE* = .11) than with a fixed assistant (*M* = 1.79, *SE* = .15), F(1,27) = 4.94, p = .035.

With respect to efficiency, Figure 4 shows that the adaptive assistant was more time-efficient (*M* = 141.22, *SE* = 11.48), overall, than the fixed assistant (*M* = 153.41, *SE* = 11.91), F(1,27) = 5.24, p = .03. Figure 5 depicts that effort did not differ across the two assistant types; however, overall effort was low.

We asked subjects their preference for the type of assistant. Although 18 of the 28 subjects (64%) indicated they preferred the adaptive assistant, this was not a statistically significant difference, $\chi^2(1) = 2.30$, p <.13.

There was no difference in knowledge about diabetes after interacting with either the fixed or adaptive computer assistant, F(1,25) = .097, p = .76. However, Table 3 shows that the subjects performed better on the second questionnaire than on the first. Thus, there was an increase in subjects' knowledge t(25) = – 3.95, p <.001.

The benefits of interacting with the computer assistant were comparable for the fixed and adaptive conditions. Results show that personal characteristics accounted for variance. Regarding effectiveness, gender, memory span, and perceptual speed accounted for 42% of the variance in number of errors made with the fixed assistant, F(3,17) = 4.16, p = .022. Regarding efficiency, the variables vocabulary, locus of control, spatial ability, gender, memory span, and perceptual speed accounted for

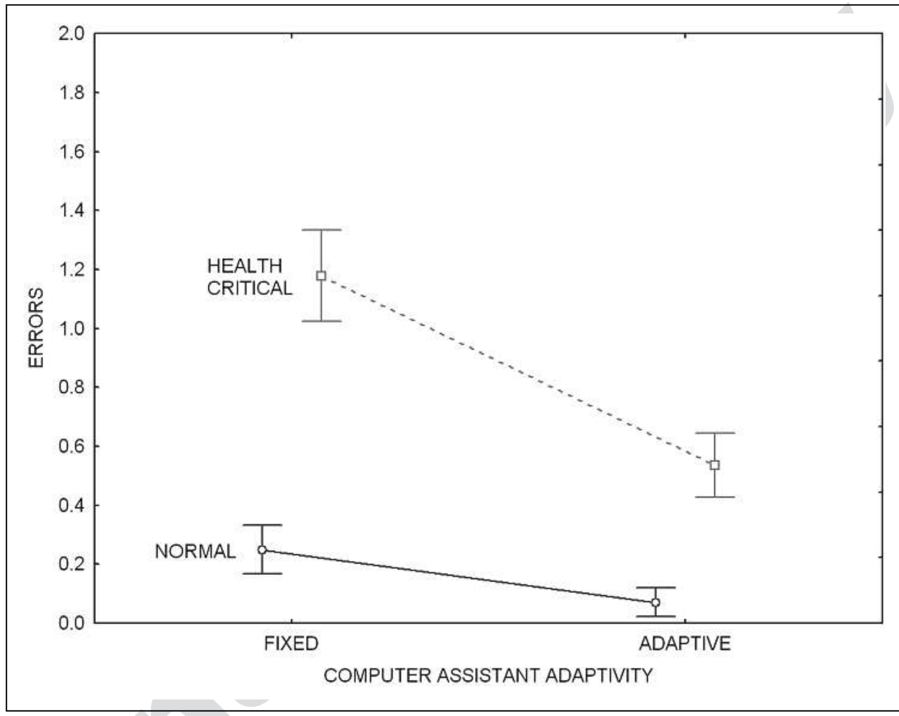

Fig. 3 Mean number of errors, with standard error bars, made in normal and health-critical situations with a fixed and adaptive computer assistant

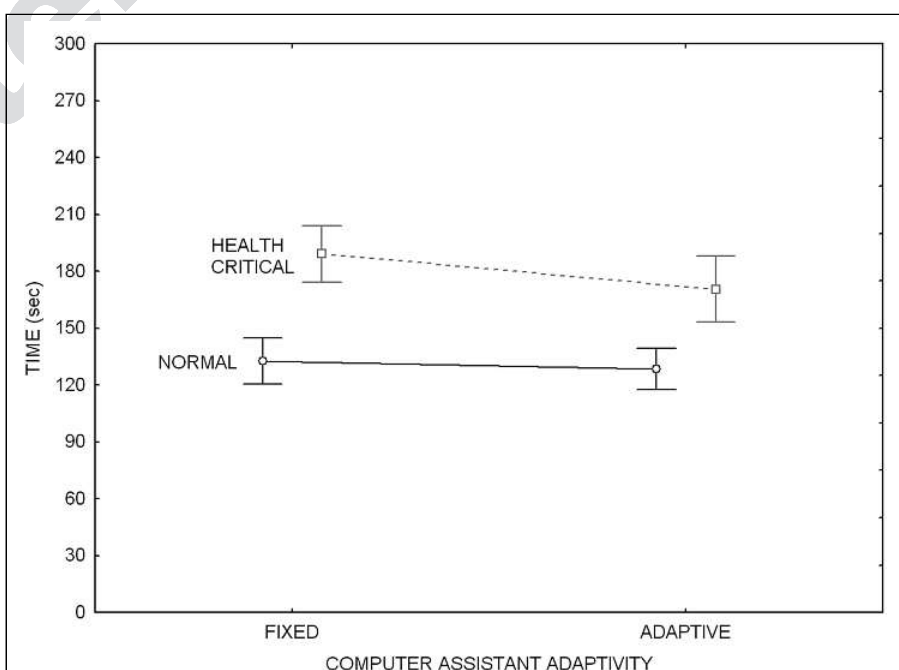

Fig. 4 Mean time required, in seconds, with standard error bars, to complete scenarios in normal and health-critical situations with a fixed and adaptive computer assistant

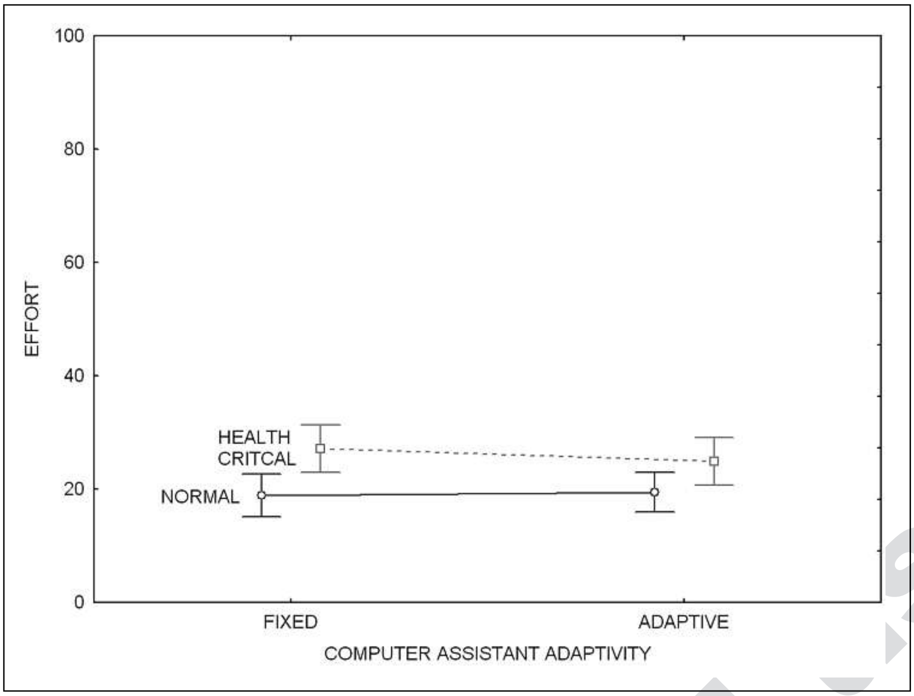

Fig. 5 Mean rating of effort, with standard error bars, experienced while completing scenarios in normal and health-critical situations with a fixed and adaptive computer assistant

Table 3 Means and standard deviation of diabetes knowledge questions answered correctly

Questionnaire	Mean	Std. deviation
Four scenarios	4.5769	1.79272
Eight scenarios	5.3462	1.78756

78% of the variance in time required to fulfill the scenarios with the adaptive assistant, $F(6,14) = 12.66$, $p < .001$. In addition, the predictors vocabulary, locus of control, spatial ability, gender, age, and memory span accounted for 81% of the variance in time required to fulfill the scenarios with the adaptive assistant, $F(6,14) = 14.73$, $p < .001$. Finally, concerning satisfaction, working memory, spatial ability, and age accounted for 43% of variation in preference for type of computer assistant, $F(3,17) = 5.51$, $p < .001$.

4. Discussion

In this study we evaluated an adaptive computer assistant designed to supervise older diabetics' self-care, support limiting illness and acute treatment, and develop health literacy. The design of the assistant was based on domain, task and scenario analyses and was developed in collaboration with the LUMC. Older adults performed activities with the assistant according to scenarios that described the daily life of a diabetes type II patient with normal and health-critical situations. We compared an adaptive assistant that adjusted its feedback to the subjects' health situation with a fixed one.

In summary, the adaptive computer assistant was more effective in dealing with normal and health-critical situations. Also, it led to more time efficiency. Overall, the subjects experienced little effort performing the scenarios suggesting that the assistant was easy to use. In addition, working with the interface and receiving feedback from the assistant enhanced the subjects' knowledge of diabetes (see Table 3). However, there was no significant preference for the adaptive assistant. Furthermore, the fixed assistant did not lead to better knowledge of diabetes type II, but our assessment may not have been sensitive enough to detect learning differences. Lastly, as we anticipated, there was a relationship between subjects' personal characteristics and their use of and preference for the assistant.

Results of our study have implications for the design of telecare technology. Integrating adaptivity in the design of computer assistants appears to increase effectiveness and time efficiency. The use of the assistant in general led to a low level of experienced effort and an increase in health literacy regarding diabetes. Consequently, use of an adaptive assistant may enable older diabetics to integrate self-care activities in their daily life, thus maintaining quality of life, enhancing health literacy, and increasing adherence to medical treatment (e.g. [4, 6]). However, users' personal characteristics, including age, gender, cognitive abilities and personality traits, can influence users' success with computer assistants.

It is important to note that the experiment only lasted several hours and was performed with older adults who did not have diabetes. Study of the long-term influence of adaptive computer assistance requires observing the use of the telecare technology over a longer period with actual diabetics. Also, further study of other methods of computer assistance such as providing multimodal feedback [24] and application of mobile devices [25], would be beneficial for further development of telecare technology.

In conclusion, the use of an adaptive computer assistant, which adjusted its feedback style to the patient, was effective and time-efficient. The assistant has the potential to help older chronically ill patients cope with their self-care, including enhancing health literacy, and consequently increasing medical adherence. When designing telecare technology, such as described in this article, personal characteristics have an influence on technology use and must be considered in the design process.

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