SuperAssist: A User-Assistant Collaborative Environment for the supervision of medical instrument use at home

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***Abstract*—With the rise of Transmural care, patients increasingly use medical instruments at home. Maintenance and troubleshooting greatly determines the safety and accuracy of these instruments. For the supervision of these complex tasks, we developed a User-Assistant Collaborative Environment (U-ACE). We designed three types of personal virtual assistants that vary in dialogue style and level of autonomy. According to the Scenario-Based Design method, we did a laboratory experiment and evaluated the influence of the different assistant types on the usability of the U-ACE. Additionally, we examined if considering personal characteristics can help better gear the assistant to the users needs. Results showed that a cooperative assistant focusing on interaction and guiding the user through the required steps, was best suited and was declared the most preferred. Collaboration with an autonomous assistant that acts autonomously led to the most efficient performance. Furthermore, personal characteristics explained variance in the experienced usability. It is recommended that, while using the U-ACE, the users select their own assistant type depending on context and personal characteristics.**

***Index Terms*—User-Assistant collaboration, personal virtual assistants, domestic medical instruments, scenario based design.**

I. Introduction

CURRENT economical climate and aging among the population force fundamental changes in western health care. More and more, health care is oriented towards Transmural and patient-centered care. This implies that patients have to be more committed and self-sufficient and perform an increasing amount of complex tasks, such as participation in development of the care policy and execution of self-care; management of a computer-based patient record (CPR), operating domestic medical instruments; and communication with (remote) medical and technical specialists. Development of digital personalized assistants (e.g., [1]–[2]), offers opportunities improved supervision of these complex tasks.

Within the framework of the SuperAssist project, TNO, Delft University of Technology (DUT), and the Leiden University Medical Center (LUMC) are developing models for the supervision of complex task environments by deployment of personal virtual assistants (Fig. 1). The project's business partners Philips Research, Pemstar, Science & Technology, and Sigmax, bring in their technology and contribute to the development and validation of SuperAssist elements [3].

The focus of this experiment is on personalized virtual assistants for supervision of medical instrument use at home. This takes place through joint user-assistant maintenance and troubleshooting technical failures (defined by the dashed frame in Fig. 1).

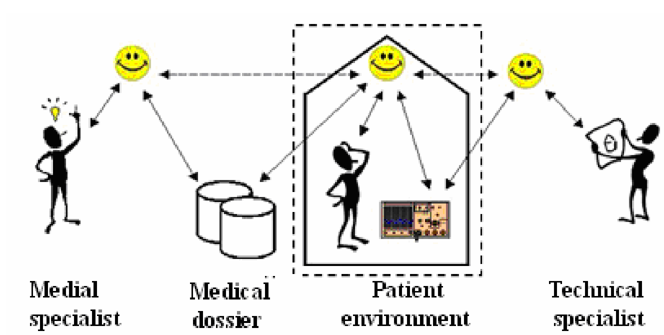

Fig. 1. Supervision of complex task environments by user-assistant collaboration

A. Complex tasks: Maintenance and troubleshooting

Maintenance is performed to eliminate system failure traps and hazards in order to ensure that equipment continues to work within designed tolerances and specifications [4]. This ensures that the defined functions and standards of operations of equipment are capable of being performed for the required period [5]. Maintenance tasks are complex due to low frequency of occurrence, operating manuals with a high information density, and the importance of handling precision. In addition, it requires distributed attention; one must keep an

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eye on the instructions, the instrument's failure symptoms, and its own actions.

Basically, troubleshooting exists of a search for likely causes of faults through a potentially erroneous problem space of possible causes [6]. Also, the different cognitive abilities such as reasoning capacities, application of knowledge, and application of human sensors are essential [7]–[8].

Existing conceptualizations of troubleshooting [9]–[13] can be integrated in four subprocesses:

1) Representing the problem (assessing discrepancies between the system's current state and ideal state);
2) Diagnosis or fault isolation, including remembering previous experiences, exploring the problem space, generating hypotheses, gathering information (observing and testing components), hypothesis evaluation and decision making;
3) Selecting, implementing and evaluating solution options, and;
4) Adding experience to personal experience library.

In an optimal situation, the subprocesses are run through once, but it is likely that a troubleshooter has to repeat a subprocess or go one or more subprocesses back before the failure is found and tackled. These subprocesses of troubleshooting give a good insight in what is required to solve technical problems and can help thinking about possible support a virtual assistant can give.

B. *User-assistant collaboration*

The integration of personal assistants that adapt to the user and provides them with support fitting their specific background knowledge, objectives, cognitive capacity, and current situation, enables distributed human and agent actors to work together and address large-scale real-world problems, e.g., [1], [2], [14]–[18]. Subsequently, we developed a User-Assistant Collaborative Environment (U-ACE) in which a personal virtual assistant supervises medical instrument use and supports the user during maintenance and troubleshooting.

Research proved that different assistant types influence user performance and satisfaction. Two major factors are dialogue style, e.g., [1], and level of automation, e.g., [19], [20]. Dialogue influences the way people will interpret, accept and, apply information given by the assistant. For example, it can disrupt the user's current activity but can also help understand better why certain action have to take place. Level of automation, ranging from the situation in which the operator is completely left out of the decision process to minimal levels of automation where the automation only provides recommendations and the operator has the final say, has a big influence on the situational awareness, creation of conceptual models by the user, and trust.

Taking into account the effect of these factors, we expect that the different assistant types will influence the experienced usability of the U-ACE (Hypotheses 1). We will look at collaboration between participant and personal virtual assistant on the processing of high-density information, handling precision, distributed attention, exploring the problem space, diagnosis and fault isolation, hypotheses generation and evaluation, and selecting, implementing and evaluating compensatory actions. We will distinguish three types of assistants. The first assistant type is manual and collaboration with this type resembles most the current problem solving approach where users refer to a paper operating manual. The second is cooperative. In this case, the assistant has an average level of automation, i.e., suggesting actions the user can perform, and the dialogue is focused on a high level of interaction with the user. Finally, we distinguish an autonomous type. The assistant has a high level of autonomy, i.e., executes automatically the necessary actions, and only reports to the user when it feels it's necessary.

The main difference between on the one hand the manual and on the other hand the cooperative and autonomous assistants is that the latter two assistants are online and react directly to the users' actions. Additionally, we expect that, because of the instant supervision, the online assistants will enable better performance and will be more preferred in comparison with the manual assistant. Therefore, we also made a distinction between the manual assistant and the two online ones. We measured the influence of the three types of assistants on the usability of the U-ACE according three standard usability requirements, i.e., effectiveness, efficiency, and satisfaction.

C. *Personal assistants*

In addition to the influence of the assistant type on usability, we expect that users react differently to complex technical tasks. People apply different strategies when confronted with technical failures due to dissimilarity in experience of assessing problems, generating hypotheses based on former experience, and the knowledge of possible compensatory actions. It is likely that the participants' characteristics, in this case biographical data, cognitive abilities and personality, influence the effect of the assistant type on the experienced usability of the U-ACE (Hypothesis 2). We will survey the participants' characteristic and analyze if they have a predictive value concerning their performance and preference.

On the one hand, the SuperAssist project focuses on older diabetes type II patients. We feel they could profit the most of the U-ACE, because they generally experience the use of medical devices, such as a glucometer or blood pressure measurement tool, as complex and it tends to trigger errors [21]. On the other hand, current U-ACE is a first concept and we want to make sure that it is suitable enough for patient supervision and support. Therefore, we used in this experiment a controlled and homogenous group consisting of a student pool. From evaluation the system with this group we can distract important effects of the assistant type and the personal characteristics. In the future we aim at including participant, who fit more the self-care patient characteristics, such as older adults, people with obesities, and chronic patients.

Fig. 2. Operating the DCA 2000+ analyzer (light gray) in a user-assistant collaborative environment (U-ACE)

II. Experiment

A. Objectives

The objective of this experiment was to test the effect of different assistant types on the usability of the User-Assistant Collaborative Environment (U-ACE) developed for the supervision of medical instruments use in the domestic setting. Furthermore we looked at different personal characteristics and their moderating effect on the participants' experience of usability.

B. Scenarios

A frequent used method to enhance the role of participants in designing solutions for future environments is the use scenarios. A scenario is a description that contains actors, background information on the actors and assumptions about their environment, actors' goals or objectives, and sequences of actions and events [22]. It focuses on active participating roles for the potential end users.

An example of a scenario in the framework of our project is the following. *Lydia (aged 61) experiences increased thirst, frequent urination at night, fatigue, and blurred vision. She visits her physician who sends her to the policlinic. Test results show that she suffers from diabetes type II. The physician prescribes her a treatment, which exist of a number of complex tasks, such as performing exercise and diet, monitoring blood glucose, and taking medication. Key issue for Lydia is combining these self-care tasks and her daily tasks while maintaining a good quality of life.*

One of the aspects of her self-care is the use of medical instruments, such as a glucometer and a blood pressure monitor. It is essential for Lydia's idea of her health status that the medical instruments must work properly and test results are accurate. In case of a technical failure, Lydia is aware of the new situation and the problem is solved. Furthermore, if necessary a technical specialist should be notified that technical support is required.

The use of the U-ACE can play an important role in the supervision of Lydia's medical instrument use. It can enable the assistant to monitor the operation of the instrument, the test results, and possible error signals. Based on this data, the assistant can support Lydia troubleshoot technical problems and help perform regular maintenance.

We developed instrument operating scenarios in which the participants played the role of a patient operating a medical instrument at home (Fig. 2). There were nine cases, consisting of three maintenance cases, e.g., cleaning the instrument, and six cases in which the participants had to solve technical failures, e.g., replacing a blown fuse.

For our study, we selected three types of assistant:

- *Manual:* The user refers to a paper manual with instruction. This assistant resembles mostly the use of current operating manuals;
- *Cooperative:* The assistant focuses on user participation and interaction, suggests possible actions, and guides the user step by step through maintenance and problem-solving processes, and;
- *Autonomous:* the assistant works individually and relieves the user of its tasks within its capacity. Ideally it independently performs diagnosis and compensatory actions and afterwards reports the actions to the user.

A case is composed of a task the participants receive and solving of failures that arose. An example of a task was to perform a "SET UP" and to verify if the instrument functioned properly. During the set up, a failure arose and the application displayed error code "E3" on the LCD display. The manual assistant refers op the official instrument operating manual. The cooperative assistant facilitates diagnosis of the problem through question and answer and guides the user through the relevant compensatory steps of action. The autonomous assistant independently performs diagnosis and performs compensatory action. It only reports the performed actions afterwards. If actions outside the autonomous assistant's ability are required, e.g. physical manipulation, the user is put back in the loop. In the example case, the diagnosis was that the program card contacts were dirty and the instrument

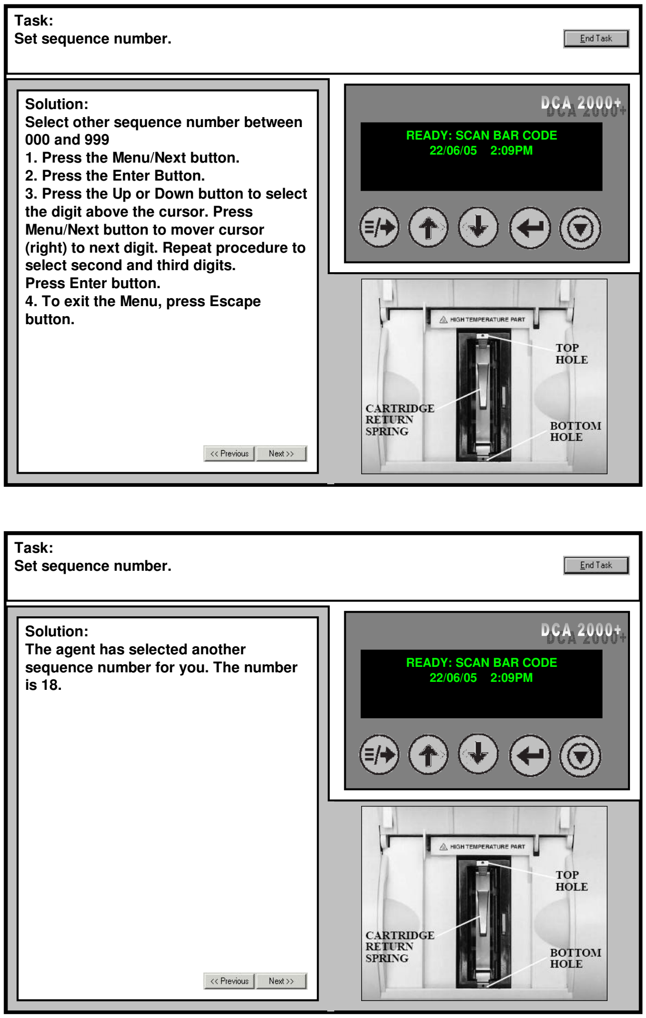

Fig. 3. Interface in User-Assistant Collaborative Environment (U-ACE) with the cooperative (above) and autonomous assistant.

couldn't complete "SET UP". The compensatory action was to clean the program card's contacts with an eraser and place it back in the instrument.

C. Participants

Twenty-nine persons participated in the experiment. The participants were bachelors and master students, aged between 18 and 36 (mean = 22). Three experiment runs served as a pilot during which the three different assistant types were tested. These results are not considered in the sampling.

D. Experiment design

We applied a between participant design and the participants performed nine tasks in one of the three assistant types. To measure the personal preference assistant type, we asked the participants to repeat one task while supervised by the two remaining assistants and rank the three different types. For the assistant to react to the participants actions, we applied a Wizard of Oz method [23]. Our current assistants are not suitable enough to really sensor users' behavior and react adequate, so the experiment leader directs the assistant during the collaboration with the user.

E. Material

During the experiment, the participants worked with a DCA 2000+ HbA1c analyzer. It is manufactured by Bayer and measures Hemoglobin A1c, the average glucose level of the patient over the previous three months. This instrument is currently used by the general practitioners and in laboratories, but it is not unlikely that in the near future cheaper and more straightforward versions will be brought on the market and which are suitable for use in the domestic situation. Due to increasing feedback, it could help the patient performing self-care more accurately and increases the adherence to the care policy. The majority of the problems presented to the participants was fictitious and do not occur in real-life operation of the Bayer DCA 2000+ analyze. The participants worked with a User-Assistant Collaborative Environment (U-ACE) interface that is displayed on a Tablet PC connected to the DCA 2000+ (Fig. 3). The top frame is the taskbar that displays the task. When the participants feel that the task is fulfilled they click the "End task" button. The dark grey frame is a replica of the LCD display and buttons. These are used instead of the original DCA 2000+ analyzer interface so that the different sources (textual and graphical support and DCA 2000+ display) that offer the information required for maintenance and troubleshooting are combined in one frame. Physical manipulation of the instrument, such as replacing parts, takes place on the DCA 2000+. The light gray field presents the textual and graphical support, and is active with the cooperative and autonomous assistant.

To prevent disturbance between the manual and online (cooperative and autonomous) assistant type, the textual and graphical support of the online assistants were literally taken from the original operation manual. No information was added and the lay-out remained the same.

F. Instrumentation

To determine the effect of the assistant type on maintenance and troubleshooting of the medical instruments, we measured the U-ACE's usability, concerning:

1) Effectiveness: the number of cases the participants could solve;
2) Efficiency: the number of errors made and missed steps, total performance time, and indication of experienced effort on a Rating Scale Mental Effort (RSME) [24];
3) Preference: the participants repeated one case in collaboration with the two other assistant and indicated their personal preference for the assistant type, mentioning a positive and negative feature and classifying the assistants according to personal preference.

To determine whether personal characteristics influenced the above-mentioned effect we surveyed the participants' biographic data, education level, and computer experience; a number of human cognitive abilities [8], i.e., reading skill, reading speed, and spatial ability; Locus of Control, which indicates the extent to which one believes that reinforcements and rewards are a function of one's own behavior (internal locus) or a function of chance, fate, powerful others, etc.

(external locus) [25], and; the participant's Personal Fear of Invalidity (PFI) that indicates individual differences in the fear of making judgmental errors [26]. To make inferences about the moderating effect of personal characteristics on preference for assistant type, it is important that the deployment of an assistant type during the experiment does not influence this preference.

III. Results

Comparing the different assistant types, analysis showed significant difference in their influence on effectiveness, efficiency and satisfaction (Hypothesis 1). Considering effectiveness, as can be seen in Fig. 4, participants working with the online assistants (cooperative and autonomous assistant) scored higher than when working with the manual assistant (F(1,24)=26.84, p<.001) and in turn, as can be seen in Fig. 5, the participants working with the cooperative assistant scored higher than when working with the autonomous assistant (1,16)=4.57, p<.05). Considering efficiency, participants working with the online assistant scored higher than the when working with the manual assistant concerning the number of errors (F(2,23)=5.39, p<.001) and the total performance time (F(2,23)=4.96, p<.05). Participants working

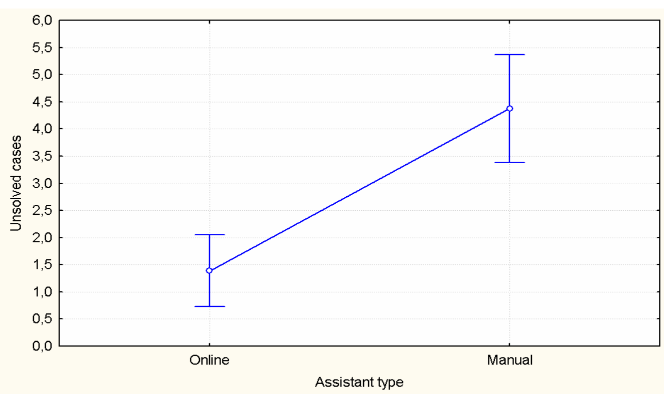

Fig. 4. Number of cases solved in manual and online assistant type.

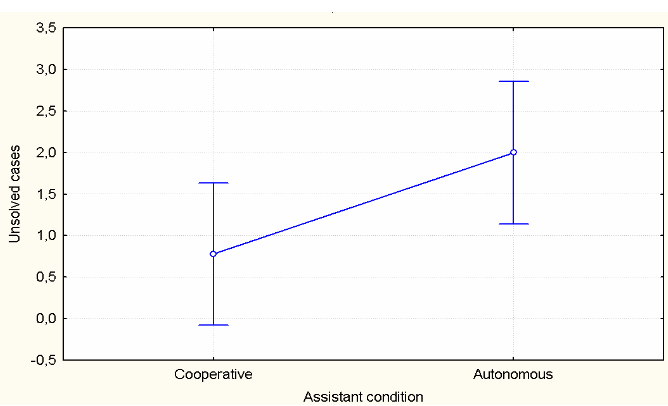

Fig. 5. Number of cases solved working with the cooperative and autonomous assistant.

with the cooperative assistant scored higher than the autonomous assistant concerning the observed errors (F(1,24)=11.23, p<.05), but when working with the autonomous assistant they scored higher than the cooperative assistant regarding the total performance time (F(1,24)=9.70, p<.05).

There was no significant effect of support condition on the participants' experienced effort. Of the 26 participants the average experienced effort was 61, which corresponds with rather much effort, with a minimum of 35 (some effort) and a maximum of 107 (very much effort).

Concerning satisfaction, we asked the participants to give their first (Pref1), second (Pref2), and third (Pref3) preference for assistant type (Table 2). There was a strong preference for the cooperative assistant. From the 26 participants, 17 indicated that their first preference (Pref1) went out to the cooperative assistant, 8 preferred the autonomous assistant and only one participant expressed the highest preference for the manual assistant. The least preferred was the manual assistant. From the 26 participants, 18 rated the manual assistant as least preferred, 6 participants indicated they preferred the autonomous assistant the least, and only 2 participants preferred the cooperative assistant the least. There was a no significant effect of the deployed assistant type on the participants' preference.

To measure the influence of participants' personal characteristics on their experienced usability of the U-ACE (Hypothesis 2), we conducted a goodness of fit ANOVA. Results indicated that variance in performance concerning effectiveness and efficiency, and in preference for assistant type can be explained by personal characteristics (Table 3). Education level and reading skill influenced the observed errors made. Reading speed and Personal Fear of Invalidity (PFI) explain variance experienced effort. Effect of computer experience and Locus of Control (LOC) explain variance in preference for assistant type.

TABLE 1
X^2 TEST STATISTICS ON FIRST (PREF1), SECOND (PREF2), AND THIRD (PREF3) PREFERENCE FOR ASSISTANT TYPE.

	Observed N	Expected N	Residual
Pref1 [a]			
Manual	1	8.7	-7.7
Cooperative	17	8.7	8.3
Autonomous	8	8.7	-.7
Total	26		
Pref2 [b]			
Manual	7	8.7	-1.7
Cooperative	7	8.7	-1.7
Autonomous	12	8.7	3.3
Total	26		
Pref3 [c]			
Manual	18	8.7	9.3
Cooperative	2	8.7	-6.7
Autonomous	6	8.7	-2.7
Total	26		

[a] $\chi^2(2)$=14,85, p<0.001
[b] $\chi^2(2)$=1,92, p=0.38
[c] $\chi^2(2)$=16,00, p<0.001

TABLE 2
THE PERCENTAGE EXPLAINED VARIANCE THE DIFFERENT PREDICTOR VARIABLES ADD FOR THE DIFFERENT CRITERION VARIABLES AND THE REGRESSION EQUATION.

Explained variance R^2 by the predictor variables	Regression equation
Observed errors (57%)	-1.98 + (education level*2.14) + (reading skill*0.70)
Experienced effort (31%)	61.91 + (0.06*reading speed) – (0.39*PFI)
Assistant preference (Pref1) (52%):	3.01877 – (1.16*computer experience) + (0.05*LOC)

IV. Discussion

Today's patients are using a great number of medical instruments at home. Precise maintenance and troubleshooting greatly determine if the use is safe and measurements are accurate. To facilitate this, we explored if these processes can be improved with deployment of a personalized virtual assistants in a User-Assistant Collaborative Environment (U-ACE). We studied if differences in the assistants' dialogue style and level of autonomy influence the usability of the U-ACE. Furthermore, we expected that users' characteristics would have a predictive value concerning the users' performance and preference.

Results showed that participants were well able to perform maintenance and solve technical problems, working in a User-Assistant Collaborative Environment, and collaborating with an online assistant (cooperative and autonomous). The manual assistant, which resembles most the old fashion process where users must consult a paper operating manual, proved relatively unusable. In addition, collaboration with a cooperative assistant resulted in performance that was most effective and it was considered the most preferred assistant type.

Examining the users' personal characteristics, we found three explanations for variance in usability. First, participant with a higher education level and better reading skills made fewer errors. Second, participants with high level of reading speed and low level of personal fear of invalidity (PFI) experienced significantly less effort. These results supports the idea that older adults, who's reading skill and speed diminish with the years, have more problem with the use of medical instruments. Finally, participants with a high internal level of Locus of Control (LOC) and little computer experience preferred the cooperative assistant. Participants with a high external level of LOC and much computer experience preferred the autonomous assistant. Thus, people who prefer to have control of their environment and are not experienced with the use of computers, such as medical instruments, will select to collaborate with a cooperative assistant; whereas, people who not feel they have much control of their environment and who are more self ensured concerning computer usage, would rather collaborate with an autonomous assistant.

Although the cooperative assistant proved most effective and most preferred, if we look at the influence of personal characteristics on variance of performance and preference, it is advised to enable the users to select one of the two online assistants themselves. Special attention must go out to the users' computer experience and the extent to which one believes that reinforcements and rewards are due to own behavior or a function of fate, chance, or others.

This is a first experiment that provides a good standing point for further development. Next, we are testing a new version of the U-ACE and it will have has three improvements. First, the user has the possibility to add experiences to a personal experience library. This gives them the opportunity to look back on their experience and more easily react to similar technical problems in the future. Second, we are testing it with older participants. We feel that older adults, who experience the most difficulties with the use of medical instruments at home, would profit even more of this system then current student participants and it's important that we also analyze their performance. Finally, we are testing if the U-ACE could support communication with a technical specialist in case that the patient can not solve technical problems in collaboration with the assistant.

V. Conclusion

In summary, we found that collaboration of users of medical instruments with online assistants improves the performance of maintenance and troubleshooting. Additionally, collaborating with a cooperative assistant that focuses on user participation and interaction, suggests possible actions, and guides the user step by step through maintenance and problem-solving processes, leads to the most effective performance and was declared most preferred. On the other hand, collaborating with an autonomous assistant working individually and relieving the user of its tasks within its capacity, leads to the most effective performance. Furthermore, choice of assistant can be explained by personal characteristics, i.e., computer experience and locus of control. Consequently, user should have to possibility to select an online assistant (autonomous or cooperative) themselves depending on their context and personal characteristics.

With the results of the discussed experiment, we progress in the development of models for User-Assistant collaborative supervision of patients in current patient-centered health care situation in which patients receive care according the Transmural care model. Mainly, clarification of the relationship between assistant type, performance, and personal characteristics helped us improve our models for safe and accurate operation of medical instruments. We expect that these models also create a foundation for research on the supervision of other health care related factors, such as self-care (e.g., medical anamneses, self-treatment, and quality of life), CPR management, and communication with location-dispersed medical and technical specialists.

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