Mental and Physical Training for Elderly Population using Service Robots

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Abstract: In this paper we present the implementation and evaluation of mental and physical exercise applications on a humanoid service robot for use in an elderly care setting. As the mental exercise application a personalized, multi-medial quiz was designed and implemented using information from participants biography. The robot acts as the quiz master, interacting with the participants in a natural and encouraging way. For the physical exercise, a variant of the "charade" game was implemented that uses machine learning from previously collected video samples and computer vision on the robot to identify the activities that participants enact. Both applications were evaluated successfully in a real life setting and highlight the potential of using service robots in elderly care settings.

1 INTRODUCTION

Demographic change across most western nations and the accompanying increase of the elderly population will have tremendous socio-economic effects in the coming years. Current German surveys show, that 22% of the German population are older than 65 years and 50% of the population are older than 45 (Destatis, 2021). Changes associated with aging will inevitably lead to an increase of people requiring nursing care. Providing an adequate care for those populations is especially challenging due to a chronic shortage of caretakers and staff in elderly care (Destatis, 2020).

Physical and mental exercise, preferably in social groups are deemed important activities to maintain health and wellbeing while also providing social exchange, which is often lacking in aging populations. These activities can increase self-reliance and reduce anxiety and the need for health- and nursing care (Elias et al., 2015).

Healthcare Technology and particularly autonomous service robots have the potential to address these challenges by reducing the need for human resources.

In this paper, we present two applications, implemented on a social robot in order to perform mental and physical exercise together with elderly people. Furthermore, we evaluated those applications in terms of acceptance, user experience and utility.

2 RELATED WORK

There are several related projects dealing with interaction strategies and designs of companion robots and social robotics in the field of elderly care or common care.

The objective of the EU project ACCRA (Agile Co-Creation of Robots for Ageing) (Fiorini et al, 2019) is the creation of advanced robotics-based solutions in order to extend active and healthy ageing. Therefore, the project developed an agile co-creation

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development process and defined a four-step methodology. The applications developed by the projects were implemented on two types of robots: (1) Astro, a large assistive robot platform, and (2) Buddy (Guiot et al., 2020) a small-sized companion robot.

The project HAPPIER (Wieching, 2019) (Healthy Ageing Program with Personalized Interactive Empathetic Robots) (aims to support healthy and active aging in the fields of (1) communication and participation, (2) health and prevention and (3) security and data protection. In order to reach the goals the project uses different assistance robots for various purposes. The robots are connected with the Internet of Things (IoT) by a secure cloud-based system.

The Care-O-bot (Graf, B et al., 2009) (care-o-bot.de) is a robot platform designed to support humans in their home environments in an active and social way. The platform implements different interaction strategies for human robot interaction in order to be a supportive service robot. The interaction strategies include social manners for different types of humans, such as elderly or younger people.

In contrast to the projects mentioned above the goals of the NIKA project are (1) the creation of interaction patterns for human robot interaction as well as (2) the development of a middleware to provide and use the patterns on different robot platforms. The patterns are used in two different types of applications on three different kinds of robots (iRobot Roomba, MiRo, Pepper). In this paper, we will introduce the designed applications to show how they can be used to support elderly people with mental and physical exercise.

3 PROJECT “NIKA”

The work presented in this paper was developed as part of the Project “NIKA”, funded by the Federal Ministry of Education and Research. NIKA explores the use of social service robots in the context of elderly care. This setting can be especially challenging, as many elderly people rarely come in contact with new technologies (like robots) and are not what is commonly referred to as “digital natives”. Additionally, elderly people often suffer from physical impairments, such as hearing or visual impairments. Designing the interactions and applications in an accessible, non-threatening and enjoyable way is therefore of utmost importance. Thus, we chose an iterative design and implementation process with several revisions of our system and applications to address these challenges. Using real life feedback from the target audience, we were able to better adapt the system to the needs and requirements of the elderly people. The evaluation was carried out in a partnered elderly care institution with clients of day-care and stationary.

4 USE-CASES

In collaboration with a partnered care-giving institution, we conducted workshops to identify two distinct use-cases and activities based on the following key factors and criteria:

1. The application must provide benefit to the clients of care institutions
2. The application must support care-givers by taking over specific, time consuming tasks
3. The application must be acceptable for staff and clients to work with
4. The application must be hold up to ethical standards

Out of several potential applications of service robots in elderly care, the application of mental and physical exercise were identified as the most important, advantageous, and well suited for the use of social companion robots.

4.1 The Robot Platform

Pepper is the world’s first social humanoid robot designed by Aldebaran Robotics, and released in 2015 by SoftBank Robotics (https://www.softbankrobotics.com/) (SoftBank acquired Aldebaran Robotics in 2015), which was able to recognize faces and basic human emotions. Pepper was optimized for human interaction and is able to engage with people through conversation and his touch screen. In addition to the recognition of human emotions, Pepper is able to perform a wide variety of actions with its head, arms, and body movement.

Figure 1: The robot "Pepper".

The robot is controlled by a dedicated, linux-based operating system NAOqi. It contains several modules that comprise the library, enabling the developer to control the robot's resources. The NAOqi system of the Pepper robot is generally identical to the NAO robot's NAOqi, so switching from working with NAO to working with Pepper is straightforward. Pepper seems to be one of the best options for implementing and research on Human Machine Interface (HMI), due to the sensors, technologies and functionalities included in its design and pre-programmed in a form of an API (application programming interface). A significant advantage of this design is its full programmability, with access to sensors (cameras, infrared) and speech synthesis and recognition.

5 MENTAL EXERCISE APPLICATION

Aging is associated with changes in cognitive function and decline in performance on cognitive tasks, including processing of information, decision-making, working memory and executive cognitive function. Exercise of mental and cognitive abilities may decrease the rate of cognitive decline seen with aging (Murman, D., 2015) and is therefore regularly offered as an activity in elderly care facilities. In order to explore the possibility and evaluate the usefulness of using a service robot to conduct those exercises, we designed and implemented a mental exercise application.

Concept. The mental exercise application was designed as a multi-media quiz application (Figure 2). The quiz format was used, as the concept and process is familiar to most people. In order to facilitate evaluation and avoid exhaustion or stress by the participants, the quiz was designed to have rounds of ten questions without any time limits. Questions are grouped into several themed categories and three difficulty settings.

The quiz supports different question formats, such as:

- Text – simple text question
- Image - text question with additional image
- Image questions - three images to choose from
- Music/sound - a sound media file is played with a textual question on the screen

The different question formats enhances exercise by activating different brain regions. It also creates a more interesting game experience for the users.

Figure 2: Quiz category selection screen, with categories: "general", "music", "sport", "nature&animals, "engineering", "history", "literature", "Film&TV".

Biography Work and Personalization. Biography work is a concept to improve cognition and promote social participation (Corsten and Lauer, 2020) (Specht-Tomann, M. 2017) often used in elderly care. Biography work shows potential for the prevention of mental pathologies, especially in older, institutionalized adults (Elias et al., 2015).

To further promote mental wellbeing and increase participation we integrated this concept into the quiz application. Ten interviews were conducted with participants of our evaluation study to gather their biographic information and interests. Based on this information, lists of questions (text, image and music) were compiled, specific to each user (Figure 3).

Figure 3: Quiz question screen – Question: "What´s the name of this musical instrument? (as shown in the picture).

Game Flow. When the application is started, the user has to select his or her name, a selection for a quiz category and the corresponding difficulty setting are being displayed on the tablet screen, mounted on the robot. After selection, the quiz content is downloaded from a server and the quiz starts. The flow chart in Figure4 shows how the game flow was designed.

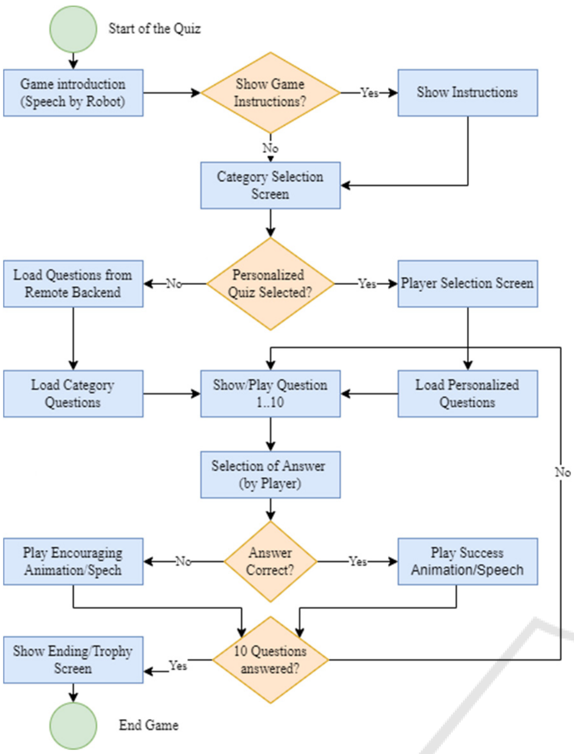

Figure 4: Mental exercise game flow.

6 PHYSICAL EXERCISE APPLICATION

Concept: The gameplay for this application is based on games like activity, charade or pantomime. They are usually played by one or more teams, where each team consists of at least two people. At the beginning of each turn, a countdown starts (e.g. by a timer or hourglass). One player of the team whose turn it is draws cards from a deck. Each of those cards has a term written on it. The player then has to pantomime so that the other team members can recognize it and guess the correct term. If the guess is correct, the team gains points. This is repeated until the time runs out. In the end, the team with the most points wins the game.

In the current prototype, Pepper robot takes over the part of the opponent team in performing and recognizing actions, which, in turn, requires the human player to mime them and vice versa. The performing and recognizing actions of pepper are classified as Round1 and Round2. The score

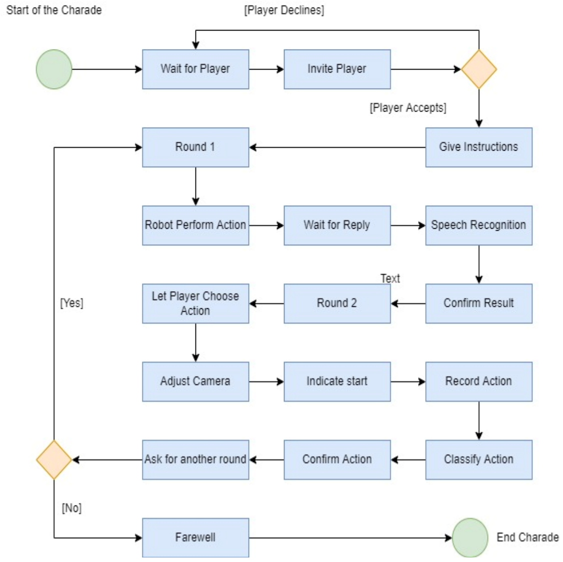

Figure 5: Charade game flow.

mechanics and the countdown have been dropped as well. Below, these simplified game rules are described as seen from the viewpoint of Pepper. A visual diagram of the simplified game is shown in Figure 4.

Explanation of Design Flow. When the application is started, Pepper uses its face detection capabilities and waits, until a person walks into its field of view (FOV). If a person is detected, he or she is verbally invited by the robot to 8 play a game of charade. If the potential player refuses the invitation, Pepper goes back into the waiting state until another face is detected. In Round1, the robot performs one of the following actions, namely: **Violin, Drums, Padding, Piano, Telephone, Tennis, Weightlifting, and Guitar,** which were

Figure 6: Charade Game activity selection, featuring activities: “boxing”, “playing the violin”, “drumming”, “rowing” and “guitar”.

stored as so called “behaviors” in the Pepper operating system. After performing the corresponding action, Pepper gives the opportunity for the human player to reply via voice command. The backend program uses speech recognition to find the correct answer based on the human player’s reply. In Round2 the robot gives a short instruction on how the Round2 is played. Afterwards, the list of possible activities to mime are displayed on the robot’s tablet, showing an illustration of the possible actions (see Figure 6).

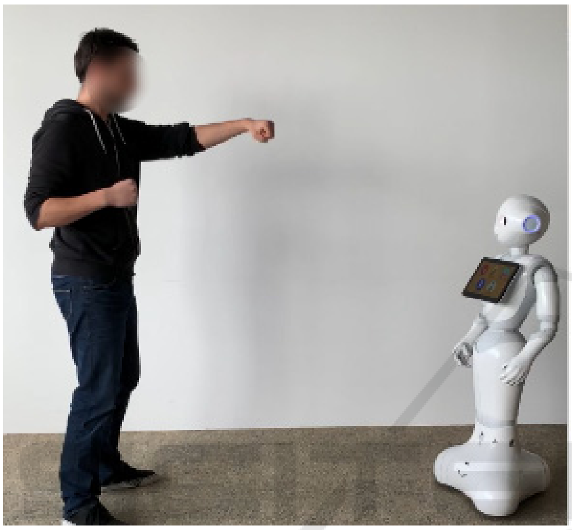

Figure 7: Performing the "boxing" activity.

Figure 8: Participant performing "violin" activity.

This approach was chosen in order to have a uniform system that does not require external components, such as game cards. As a next step, the robot adjusts its camera, so that the human player’s upper body is located in the center of the captured image data. This step is essential, otherwise the body parts important for the human action recognition (HAR) (i.e. the arms and the upper body) might not be visible, making recognition much less accurate. Furthermore, in combination with face detection, it ensures that the user is visible from a frontal perspective. After adjusting the camera, Pepper indicates to the player to start with the performance of the previously selected activities by counting downwards from 3. Subsequently, the user is recorded by the robot’s camera and the data is processed as described in the subsection below. Using the extracted features, the classification is conducted. Pepper then vocalizes its guess and asks for confirmation. If the probability, returned by the HAR system, is too low, the robot notes that it is unsure about the correctness of its guess. Depending on the correctness of the answer by the human player, Pepper gives a positive or negative response. Regardless of whether the action has been classified correctly or not, the player is asked if he or she wants to play another round. If so, the application goes back to the point where the user has to choose an action. Otherwise, Pepper says its farewell and the application stops.

The Human Action Recognition System. A fundamental challenge that arises in recognizing human actions is variability. Human movements can be influenced by multiple factors. Sheikh identified three important reasons that can result in large variability (Sheikh et al., 2005): (1) viewpoint, (2) execution rate and (3) anthropometry of actors. In our application specifically, age can greatly affect the way elderly people move. Compared to younger people, the elderly move differently in terms of velocity, flexibility and smoothness of motion. This may especially have an effect on the variability of execution rate as elderly people may perform an action more slowly.

We implemented a HAR system (Ponzer 2020), which is used for action recognition during the execution of the simplified charade game. The recognition is bound by the following constraints that result from the use-case:

Indoor Environment. In the course of the NIKA project, Pepper is only used in indoor environments, such as care facilities and assisted living homes. Accordingly, recognition has to focus on indoor situations.

One Person in FOV. During the course of implementation it was assumed that only one person is standing in front of the robot. Therefore, no segmentation was necessary in order to extract the image segment containing the player.

Frontal Perspective. The HAR system is designed under the assumption that the player is looking at Pepper and his or her body is positioned in front of the robot, as argued by Fasola and Mataric (Fasola and Mataric, 2013). The pipeline of the HAR system introduced below is divided into three main parts. Firstly, in the pre-processing step, the video frames are passed on to OpenPose (Z. Cao et al., 2019) in order to extract human skeletons from the images. Secondly, taking the skeletons as input, feature extraction is conducted. Thirdly, the features are encoded and classified by combining the global alignment kernel (GAK) with a multi-class Support Vector Machine (SVM). The pipeline is also shown in Figure 9.

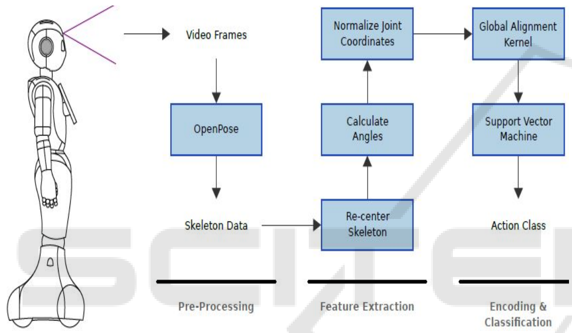

Figure 9: Player activity recognition pipeline.

Pre-Processing. The pre-processing step described in this subsection and is applied in order to bring the raw video frames into a format that can be used for further processing. In 1973, Johansson (Johansson, 1973) inspected the visual representation of human motion patterns. His work, which is considered a milestone in the research of skeleton analysis (Saggese et al., 2019), concluded that human actions can be adequately described by the appropriate selection of 10-12 joints. Therefore, joint locations or joint angles offer a rich source of information for vision-based HAR (Poppe, 2010).

Training of the Human Action Recognition System. The machine learning approach of the HAR system involves the two stages: training and testing (Lara and Labrador, 2013). The following section describes the process of training in more detail.

In the training phase of the HAR model, the sequences of the charade dataset for elderly people was recorded with participants during the project are used as samples. The dataset consists of 300 samples for each of the five classes: boxing, drums, guitar, paddling and violin. The time-consuming task of extraction of 2D skeleton data, every time the training is executed, has been completed beforehand, using the OpenPose framework. Before the execution of the training phase, the dataset was split up, as proposed by (Chicco, 2017). 20% of the samples are withheld for the evaluation phase while the remaining 80% were used for training of the classifier. Accordingly, the model is trained on 1200 samples and tested on 300 samples. In order to test under conditions that are similar to the planned use-case, the split between training and testing data was done at the level of the

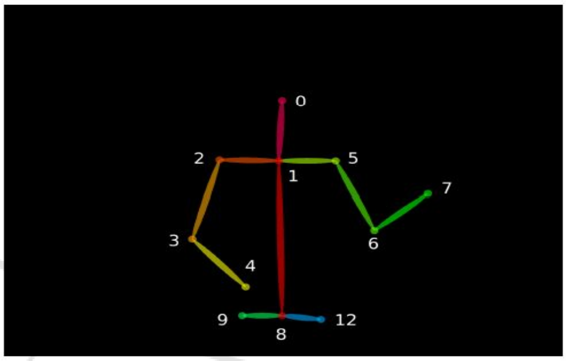

Figure 10: Open pose derived skeleton.

individual actors. Thus, each actor, is either in the training, or in the test set.

For the purpose of classification, the recognition system, as described in Figure 9, is composed of a multi-class SVM. For measuring of the similarity between the time series, the SVM is combined with the GAK as the kernel. Although the improved version of the GAK, namely the Triangular Global Alignment Kernel (TGAK), can be computed faster, this comes at the cost of accuracy. As mentioned in the previous section, with the large amount of data used for training as well as during the application's execution, the GAK's computation is still possible in a reasonable time frame. We therefore, chose to use the original kernel. The input for the classifier is windowed to a length of 50, which means that the concatenated features of 50 consecutive frames are used to represent one sample.

Performance Results of our HAR Model using the Charade Dataset. The performance results of the proposed model are summarized in the following table. It contains the corresponding evaluation scores for each class, namely precision, recall and the F1-score. The average accuracy over all classes on the test set is 6% less than on the training set, i.e. 84.4% instead of 90.4%.

Table1: Precision, Recall and F1 Score of the different activities.

	Precision	Recall	F1-Score
Boxing	0.77	0.95	0.85
Drums	0.81	0.77	0.79
Guitar	0.90	0.70	0.79
Paddling	0.98	1.00	0.99
Violin	0.79	0.80	0.80

7 EVALUATION

The evaluation was considered one of the most important phases of the NIKA project as it offered the opportunity to gather real world data about use of humanoid service robots in elderly care settings. It was carried out in several iterations with focus on different aspects. The main goal of the evaluation was to examine the feasibility of the technology, e.g.: Is it possible to run the applications smoothly on site under real world conditions with current state of the art robots? Furthermore, the interaction of the senior citizens with the robots and the usability of the quiz and charade applications were examined.

Since the Quiz and Charade applications were mostly focused on helping the mental and physical activity of elderly people, most of the evaluation took place in an elderly home of the partnered Elderly Care organization "Wohlfahrtswerk für Baden-Württemberg".

As the project was carried out during the global covid pandemic, the originally planned evaluation had to be adapted to the circumstances. For this reason, the first evaluation phase was done during the lockdown phases, with questionnaires sent to the participants and without direct robot interaction. The objective was to gather information about the needs and opinions of the elderly people in regards to the interaction with service robots and our specific use-cases.

Evaluation Timeline: From January to December 2021, a total of four evaluations were conducted in a care facility of the Wohlfahrtswerk organization.

April 2021: First iteration of the cognitive activation "Quiz" (5 participants). The participants each played two rounds of quizzes, in which they could choose one category each.

August 2021: Second iteration of the cognitive activation "Quiz" (15 participants). The participants each played two rounds of quizzes, in which they could choose one category each.

Figure 11: A study participant playing the quiz game.

October 2021: First iteration of physical activation "Charades" (10 participants). Participants played one round of charades (6 movements in total) and were allowed to choose whether to play a second round.

November 2021: Third iteration of the cognitive activation "Quiz" (10 participants). The participants played two rounds of the quiz. In the first round, they could choose a category. The second round was "My personal quiz," in which the content from the pre-interviews was personally created. An observation sheet was used to record social, physical, and cognitive activity, as well as mood and well-being. Likewise, any technical issues were recorded so they could be ironed out for the next iteration.

Participants: In the run-up, the participants were acquired with the help of flyers and with the support of the social service management and fixed appointments were assigned. The selection was based on the following criteria:

- at least 65 years old
- home care environment
- interest in technology and basic understanding
- no major cognitive impairments

- ability to read and write (if necessary by means of aids)

Equal gender and age distribution was also taken into account. In order to ensure comparability of the results, the same persons were asked again for the following iterations. Each participant was given the same time window of 60 minutes.

Methods: The following methods were used in the evaluation:

- Pre-interview (only for third quiz evaluation in November '21).
- Questionnaire (pre-evaluation)
- Observation
- Questionnaire (post-evaluation)

Pre-Interview: A special feature of the quiz concept is the possibility of personalization, i.e., tailoring question content to one's own interests and biographical events. In order to be able to evaluate a very high degree of personalization, the participants were interviewed in advance and a personal quiz was generated from their answers.

Questionnaire (pre-evaluation): After welcoming the participants, they were asked about their socio-demographic data (age, gender, etc.), interest in technology and awareness of robotics before using the robot. For the charade use-case, questions about physical activity were also included.

Observation: After the survey, the participants were given a short introduction to the system (quiz or charade) and could test the system independently.

Questionnaire (post-evaluation): After playing the quiz, the participants were asked about their experience of use with the help of a questionnaire.

a) Questionnaire on the quiz: This consisted of a part on the quiz (including the use of the Game Experience Questionnaire in August and November), on usability (System Usability Scale) and questions on the use of the robot assistant. The questionnaires of the three iterations were similar except for the addition of the GEQ from August and further questions on the use of the assistant robot.

b) Questionnaire on the charade: This consisted of a part on the charade (among other things, survey of activity and fatigue after the charade, Game Experience Questionnaire). Likewise, the usability was surveyed by means of the System Usability Scale. Finally, questions about potential usage were also asked here.

The iterative approach enabled the project team to incorporate user feedback directly into the system after evaluation. Thus, technical problems could be identified and solved and the quiz concept could be adapted and improved. Even though only one iteration was possible for the charade, the system could be further developed with the help of this.

The questionnaires contained both quantitative and qualitative items. The quantitative data were analyzed and presented descriptively. The scales used (GEQ and SUS) were evaluated according to the specifications. The qualitative evaluation was carried out by means of a descriptive interview analysis, in which the statements in own words are classified in selected outlines by means of paraphrasing. The data was transcribed and analyzed using Mayring's content analysis (Mayring, 2004). The results were discussed with the partners promptly after the iteration in order to be able to incorporate important findings into further development and the next iteration.

8 RESULTS

In summary, the system (Pepper with quiz/ Pepper with charade) was very well received by the users. The SUS score of the System Usability Scale was always in the range of "good to excellent" (80 to 100 points) for the quiz and in the range "good" for the charade. Overall the quiz application reached higher scores in terms of enjoyment (Figure 12, 13) by the majority of participants.

These results need to be contextualized with the fact that the concept of the charade game was mostly unknown for the participants, contained more advanced game mechanics and technologies (computer vision, machine learning), limited by the robots functionalities and thus was more prone to errors (e.g. in the detection of the user actions and speech recognition). In contrast, most participants were used to playing quiz games from real life experience or mobile device apps and understood the concept and their required actions much more intuitively.

The results of the GEQ of both applications are presented in Figure 14. Overall, the experience evoked little negative feelings or tension but high feelings of immersion with a positive affect.

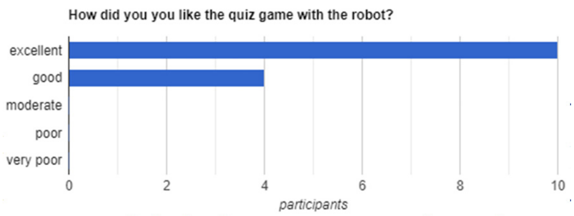

Figure 12: Overall quiz game evaluation.

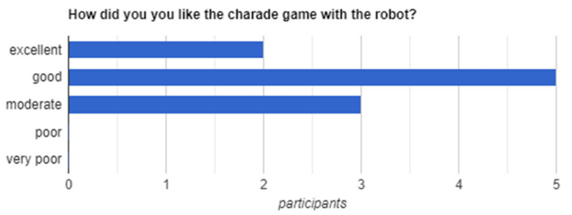

Figure 13: Overall charade game evaluation.

participants can relate to. Regarding the activities that the robot performed, the activities of playing the violin and the guitar were regarded as hard to distinguish. In addition, the sluggish movements of the robots were sometimes criticized (mostly a limitation of the robotic platform used).

Due to the number of participants in our studies, they cannot be considered statistically significant. Nonetheless, our results yield interesting insights into the real world application of the use of service robots in elderly care for different use cases. More researched is needed to validate these results using bigger sample sizes and longer-term application.

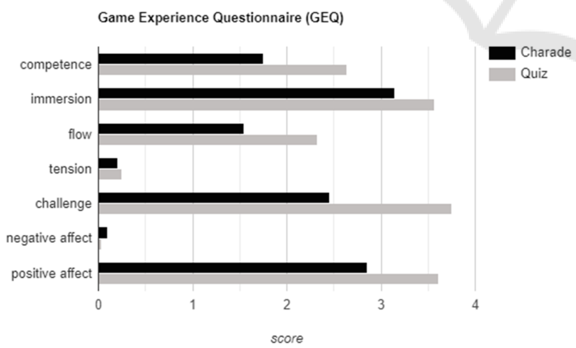

Figure 14: Game Experience Questionnaire Results.

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