Real-Time Feedback on Older Adults Exercise: A Socially Assistive Robot Coaching System

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***Abstract*—Physical exercise is crucial for promoting and maintaining the health of middle-aged and older adults. As the elderly population grows, effective coaching methods are increasingly necessary. Most current coaching systems lack clear reactive and objective feedback options. This study introduces a multimodal system featuring a socially assistive robot that guides individuals through exercise routines while providing encouragement and feedback. The system includes a heart rate sensor and physical motion monitoring, allowing the robot to offer real-time suggestions based on user performance. A graphical interface mirrors the user's movements and displays information on heart rate, kinematic data, scores, and next steps. This study evaluates the performance of two robots (NAO and Pepper). It investigates whether different robot embodiments—such as physical appearance and size—influence users' perceptions through a within-subjects approach. Questions from the Robotic Social Attribute Scales (ROSaS) assessed users' feelings of competence, warmth, and discomfort towards the robots. Elements from the Unified Theory of Acceptance and Use of Technology (UTAUT) measured performance expectation, effort expectancy, and social influence. Nineteen adults aged over 40 completed a series of upper-limb exercises. Both robots effectively communicated the exercises and corrected participants' movements. Participants found the system engaging and anticipated that it would be well-received by others, regardless of the robot used.**

***Index Terms*—Exercise Coaching, Middle-Age, Older Adults, Real-Time Feedback, ROSaS, Socially Assistive Robot, UTAUT**

I. INTRODUCTION

In October 2020, the World Health Organization (WHO) initiated the Decade of Healthy Ageing for 2021–2030, addressing the swift rise in the global middle age and elderly population [1]. Currently, more than one billion individuals (12%) are over 60, with projections expecting this number to double to 2 billion (22%) by 2050 [2]. As populations age, physical activity (PA) becomes crucial in maintaining health and functional capacity among older adults. Despite the well-documented benefits of exercise—including the prevention and management of non-communicable diseases, reduction of depression and anxiety symptoms, enhancement of cognitive functions, and overall well-being improvement [3], middle age [4] and older adults [5] remain largely sedentary and unmotivated. Some of the most common reasons for not doing enough physical activity are related to lack of time, social support, and motivation [6].

Traditional interventions designed to promote PA among older adults typically involve structured exercise programs at community centres and health clubs, supplemented by educational outreach on the benefits of exercise. However, these programs often face significant challenges, including limited accessibility for those with physical constraints, insufficient engagement due to a lack of diverse, culturally relevant activities, rigid schedules that do not accommodate varying abilities, and a general lack of personalized motivational strategies [7], [8] [9]. These shortcomings highlight the pressing need for innovative, technology-enhanced solutions such as socially assistive robots (SARs), which offer customizable and accessible exercise options, real-time feedback, and interactive capabilities tailored to individual needs in home environments [10]–[12]. SARs are robots that provide assistance through social rather than physical interaction, aiming to motivate and engage users in activities that improve their health and well-being without direct physical contact [13].

Research on SARs in health contexts highlights their potential to enhance physical and mental health outcomes. Particularly in incentivizing exercise among older adults, SARs have demonstrated efficacy in improving engagement and adherence [14], [15]. Stroessner and Benitez [16] explored how humanoid and non-humanoid robots with gendered and machinelike features impact social perception, finding that these characteristics can alter users' attitudes and expectations. Guneysu *et al.* [17] and Ramgoolam *et al.* [18] employed NAO robots to show positive effects on motivation and exercise performance among various age groups. Similarly, studies involving the Pepper robot, such as those conducted by Robinson *et al.* [19], have demonstrated its effectiveness in promoting physical activity and enhancing user engagement due to its advanced interactive capabilities and human-like appearance. However, while embodiment has been found to significantly affect preference and compliance [20] and has been identified as an area of interest [21], few studies have explored its impact on participant's preference

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and compliance in exercise execution [22]. As highlighted in recent publications, particularly by Shao *et al.* [21], this remains a gap in the literature and should be explored in future research efforts.

By comparing two humanoid robots, the NAO and Pepper, this study aims to bridge the gap by investigating how variations in their physical appearance and size influence exercise outcomes and user experience. Furthermore, this study also introduces a new Open-Source[4] real-time feedback system to complement a SAR, employing multimodal inputs and motivational interactions, designed to enhance exercise adherence and effectiveness among middle-aged and older adults. This approach addresses a gap in the literature on technology-enhanced health interventions, potentially offering significant improvements in managing age-related health issues. A supplementary video accompanying this paper offers enhanced understanding and visual insight into the system's operation and user interactions.

II. MATERIALS AND METHODS

A. System Description

The feedback system is composed of four hardware modules: (I) a wearable sensor, (II) a socially assistive robot, (III) a camera, and (IV) a screen for the GUI (Fig. 1). Communication, recording, and data capture between the different modules are achieved through a Flask Server running on a computer.

I. **Wearable Sensor:** The Polar Verity Sense sensor (Polar, Finland) [23], a wearable heart rate monitor, is attached to the participant's lower arm, connected wirelessly to the server via Bluetooth. The user's heart rate is returned every second.

II. **Humanoid Robot:** The NAO [24] and PEPPER [25] robots (Softbank Robotics, Japan) are used as instructors in the application. These robots have been commonly used in exercise applications [26]. Both are humanoid robots with synthesized voices and speech recognition, making them capable of illustrating exercises, providing feedback, and interacting with users.

III. **Camera:** A Logitech BCC950 ConferenceCam (Logitech, Switzerland) camera is used to track the user. The captured stream is processed with Mediapipe [27] to monitor the user's body kinematics and provide joint angle data in real-time.

IV. **Screen and Graphical User Interface (GUI):** A simple user interface displays real-time information to the user during the activity. It shows the number of completed movements in the current exercise, heart rate, a mirror image of the participant with joints emphasized, and the current action state (i.e., going up or down).

Thus, the setup and each of its components provide the following significant features during fitness training: (i) monitoring the user's status, (ii) illustrating the exercise routine and providing motivation, (iii) monitoring the execution of the activity, and (iv) maintaining a log of exercise quality and intensity.

1) Exercise Routine: The exercises used in this study were inspired by Kothig *et al.* [14], based on the American College of Sports Medicine (ACSM) recommendations. Participants performed three different exercises for 120 seconds each: (a) single folding arm forward, (b) folding arms forward, and (c) arms raised (Fig. 2).

a. **Single folding arm forward:** The participant holds one arm at their side, then flexes their shoulder and elbow until the arm is parallel to the ground. After a pause, the participant returns to the original position.

b. **Both folding arms forward:** The participant repeats the previous exercise with both arms simultaneously, flexing their shoulders and elbows until both arms are parallel to the ground. After a pause, the participant returns to the original position.

c. **Arms raised:** The participant performs shoulder flexion by lifting both arms from their sides until they are fully perpendicular to the ground, then returns to the rest position. During this movement, both arms must remain extended at all times.

If the participant desires, they can say "Stop" anytime during the interaction to stop it. The user can also say "Pause" and "Continue" to respectively interrupt and resume the application.

2) Exercise Performance Feedback: To evaluate whether the exercises were executed correctly, specific rules regarding the angles of each limb were defined. All upper-limb angles were measured relative to the camera, constrained to two dimensions. Using Mediapipe, the angles of the left and right arm and forearm were calculated relative to the camera's x-axis. Angles close to 0° indicate extension of the limb, and angles close to 180° indicate complete flexion. For activities (**a**) and (**b**), a target flexion of 90° was set for the forearms, with an error window between 70° and 130°. Meanwhile, participants were instructed to keep the arms parallel to the ground, with a ±30° error window. For activity (**c**), arm flexion was the criteria, greater than 150° for the forearms and beyond 160° for the shoulders. A shoulder value below 30° and an elbow value beyond 160° is expected for the rest position. All exercises were divided into phases of motion (up or down) based on the current direction of movement. If the phase is "up," participants needed to lift their arms to perform the movement. If the phase is "down," participants needed to lower their arms back to the torso. Joint speed over a small time window was used to determine whether the participant was performing upward or downward movements.

A movement is only counted as correct if both parts have been completed correctly. If an error is detected in an exercise, a message detailing the incorrect movement is sent to the robot, specifying the mistake and the exercise. For the single arm folding forward (**a**), the message will specify which arm is involved. Two categories of mistakes, each

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[4] Code available at: https://github.com/Assistive-Robotics-Lab/ExerciseFeedbackOnSocialRobot

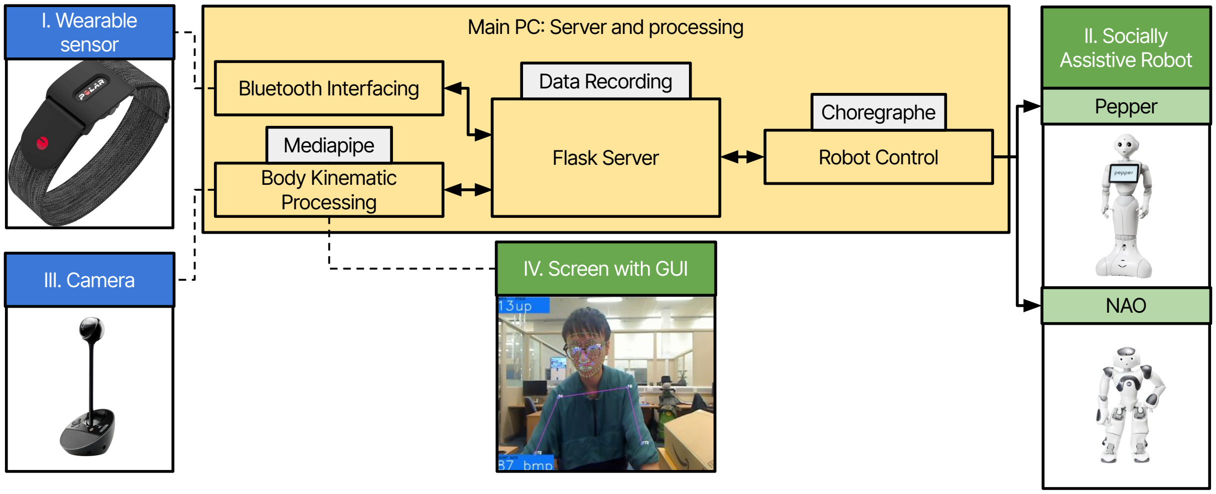


Fig. 1. General system architecture, showing hardware components and information flow.

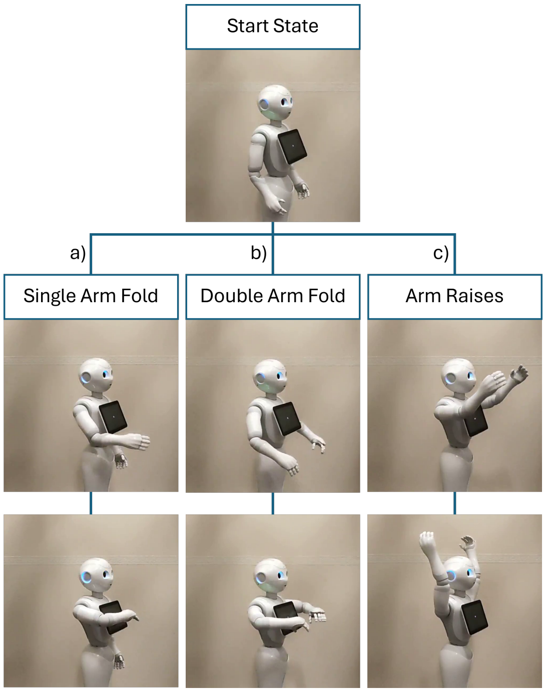


Fig. 2. Sample exercises demonstrated by the Pepper Robot

covering different types of errors, were defined:

- Inadequate movement: (i) When lifting the arms, the user does not raise the arms high enough to meet the standard, indicating that the shoulder angles did not reach the required range. (ii) When lifting the arms, the user does not close or extend the elbow joints sufficiently compared to the standard, indicating that the elbow angles did not reach the required range. (iii) When lowering the arms, the user does not return their arms to the torso.
- redundant movement: (i) When lifting the arms, the user raised the arms too high compared to the standard, indicating that the shoulder angles exceeded the acceptable range. (ii) For the single arm folding forward exercise, the user lifted both arms simultaneously instead of alternately.

For example, when the user is performing both arm folding forward exercises but not lifting the arms high enough, the robot will say, *"When you lift your arms to the highest point, please raise them a bit more to ensure they are parallel to the ground."* In the corrective feedback, the robot will inform the user of their mistake and provide instructions on how to correct it. Conversely, if the robot receives a message indicating the movement was performed correctly, it will praise and encourage the user with different phrases.

3) User Status: As per the ACSM's guidelines for exercise testing and prescription [28], the maximal heart rate and recommended boundaries for low and high heart rates were estimated using (1)-(3) as follows:

$$\textbf{Maximal bpm} = 220 - \textbf{user's age} \tag{1}$$

$$\textbf{Low bpm} = 50\%\ \textbf{Maximal bpm} \tag{2}$$

$$\textbf{High bpm} = 85\%\ \textbf{Maximal bpm} \tag{3}$$

For a heart rate within the normal range, the robot behaviour will not change, and will keep providing movement feedback. In this state, the eyes will be kept green. If the heart rate exceeds the upper bound, the robot will instruct the user to slow down their movements and adjust their breathing, with the robot's eyes turning red as visual feedback. If the high heart rate persists for 60 seconds, the session will be stopped. For a heart rate below the lower bound, the robot will encourage the user to speed up their movements, and the light of its eyes will turn blue.

B. Experimental Design

For each robot, participants performed the three exercises, completed a questionnaire, took a brief break, and

(a) (b)

Fig. 3. User setup with (a) NAO robot and (b) Pepper robot, along with the user interface screen, camera, and wearable heart rate sensor for each robot.

then switched to the other robot. The order of robots was randomized. The main outcomes of the experiment include questionnaire responses, exercise repetitions, user comments, and exercise execution, controlled for demographic factors. All sessions took place at the facilities of the Bristol Robotics Laboratory. The project was reviewed and approved by the University of the West of England University Research Ethics Committee as a low risk study, under registration code 1514. Prior to participation, all individuals were provided with detailed information about the purpose, procedures, potential risks, and benefits of the study. Written informed consent was obtained from each participant, ensuring they understood that their involvement was voluntary and that they could withdraw from the study at any time without any consequences. All collected data were anonymized by assigning unique codes. Data was securely stored on encrypted, password-protected devices accessible only to authorized members of the research team.

The test setup for the user study is shown in Fig. 3. The user stands approximately one meter away from the robot. The NAO robot was positioned on a table to match the height of the Pepper robot. A camera was placed roughly two meters from the participant to fully capture their torso, enabling real-time acquisition of joint angles (shoulders and elbows). A feedback screen next to the camera updated the interface for each exercise. Participants wore a Polar Verity Sense sensor to monitor their heart rate. Before each interaction, the wearable sensor and robot were disinfected with antibacterial wipes.

The interaction is summarized in Fig. 4. Upon arrival, participants underwent a brief debrief session, which included preparation and system calibration. Participants then signed a consent form. At the beginning of the interaction, the assistive robot demonstrated the exercises and asked the user to imitate and follow them for 10 seconds. The robot then checked that the correct posture had been achieved and provided feedback on any necessary adjustments. The main interaction then began. Each exercise session lasted 2 minutes, after which participants were given a 30-second break to cool down. The complete session, including all three exercises, took approximately 10 minutes per participant. To prevent overheating, the robots did not execute the exercises together with the user during the main interaction, only providing verbal guidance.

1) Questionnaires: To understand how users perceive the robots as social entities, a questionnaire based on the *Robotic Social Attributes Scale (RoSAS)* [29] was administered after each activity with each robot. Participants rated their opinions on different attributes of the robots on a Likert scale. These attributes represented three categories: *Competence* (Reliable, Competent, Interactive, Capable), *Warmth* (Sociable, Happy), and *Discomfort* (Strange, Awkward, Dangerous, Awful).

To evaluate user acceptance of the robots as coaches, a questionnaire based on the Unified Theory of Acceptance and

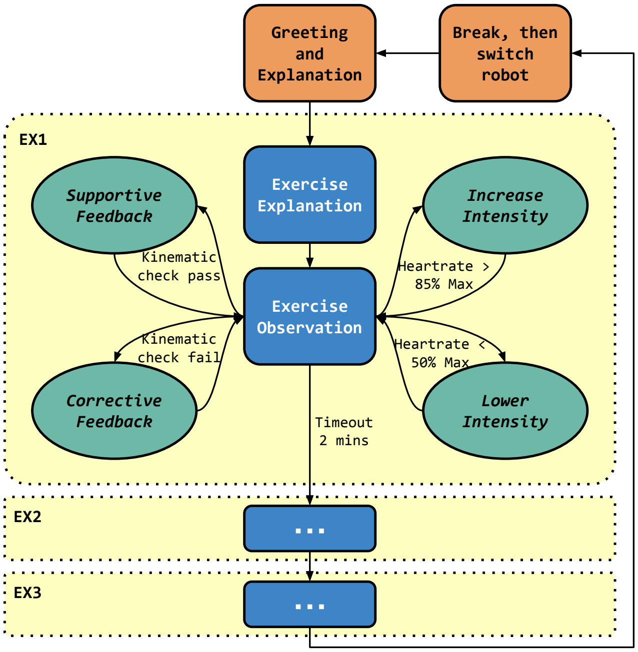


Fig. 4. Overview of experiment and robot routine.

Use of Technology (UTAUT) [30] was prepared. Questions from various criteria were selected, as shown in Table I. Questions from the *Performance Expectation* category were included to measure the users' expectations of improvement. *Effort Expectancy* questions assessed how easy the robot was to use. Finally, *Social Influence* questions evaluated how much important others influenced the perception that users should use the system. For social influence, we distinguished between the robot as a standalone unit and the robot with external systems to account for differences between SN1a and SN1b.

TABLE I
QUESTIONS INCLUDED FROM THE UTAUT SURVEY

Area	Code	Question
Performance Expectation	RA1	a) I felt the robot enables me to do exercises more efficiently.
	JB5	b) I felt the robot helped me with exercises.
	EM	c) I felt very motivated to do the exercises by the robot.
Effort Expectancy	PEU6	a) Using the robot was easy.
	EU3	b) Using the robot, heart rate sensor, and camera together was easy for me.
Social Influence	SN1a	a) I believe that people would use the robot to help them with exercises in their daily routines.
	SN1b	b) I believe that people would use robots, heart rate sensors, and cameras to help them exercise in their daily routines.

2) *Participants:* Healthy adults aged between 40 and 75 years were invited to participate in the study. Inclusion criteria included a height between 140 and 200 cm, no cardiac disease, and no significant limitations in upper limb movement. All participants signed an informed consent sheet.

Participants were asked to provide demographic information before the study, including age, weight, height, and gender. Age was used to set a target heart rate ((1)-(3)). Nineteen participants were recruited, with demographic information summarized in Table II. The average age was $54.25(\pm 6.22)$ years, with a range from 43 to 66 years. Three participants reported musculoskeletal injuries, and two reported hearing loss. None of the participants reported experiencing memory difficulties.

TABLE II
DEMOGRAPHIC INFORMATION FOR USERS

Category	Subgroup	#	%
Gender	Female	4	21.1%
	Male	15	78.9%
Highest Education Level	High school	1	5.3%
	Degree	4	21.1%
	Postgraduate	1	5.3%
	Undisclosed	5	26.3%
	PhD	8	42.1%
Musculoskeletal Injuries	-	3	15.8%
Hearing Loss	-	2	10.5%
Gaze Correction	-	9	47.4%
Total Number of Participants	-	19	100%

TABLE III
USER REPETITIONS AND INSTANCES OF CORRECTIVE FEEDBACK BY THE ROBOT, ORGANIZED PER EXERCISE

Exercise	Robot	Total Attempts (#)	Feedback Instances (#)
Ex 1	Pepper	7.39 (±1.54)	1.72 (±1.87)
	Nao	8.16 (±1.01)	2.00 (±2.00)
Ex 2	Pepper	6.74 (±1.56)	3.00 (±2.03)
	Nao	6.42 (±1.39)	3.26 (±1.59)
Ex 3	Pepper	7.79 (±1.03)	1.68 (±1.77)
	Nao	7.95 (±1.35)	2.05 (±2.34)
Combined	Pepper	7.20 (±1.43)	2.14 (±1.96)
	Nao	7.61 (±1.45)	2.44 (±2.05)

III. RESULTS

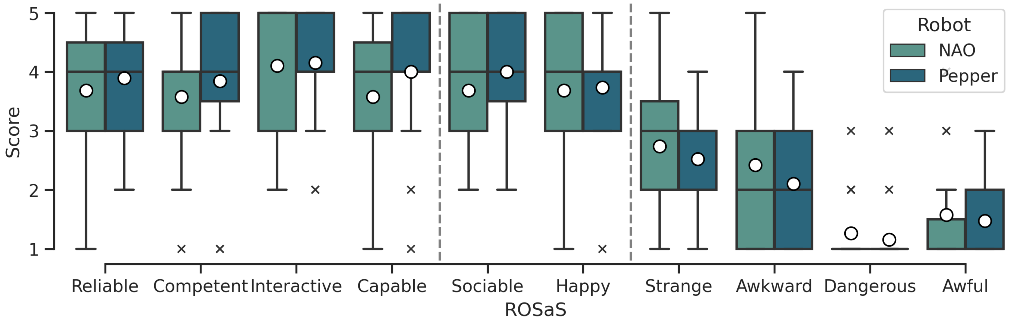
Participants completed the exercise routines, with the total number of repetitions recorded in Table III. The completion times for exercises one through three were $127.31(\pm 4.52)$, $129.41(\pm 5.99)$, and $125.42(\pm 4.93)$ seconds, respectively. All participants were responsive to the robot's instructions, and no participant requested the robot to stop. Five participants were observed to talk naturally to the robots despite no complex voice interaction being implemented. We used the Mann-Whitney U test to analyse the questionnaire responses between the two robot conditions.

A. RoSAS Questionnaire Scores

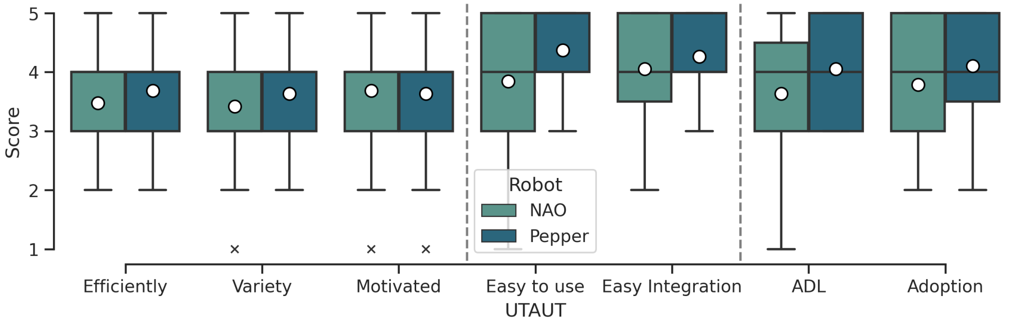
Fig. 5a shows a box plot for the results from the questions from the ROSaS questionnaire data. No significant difference ($p - value < 0.05$) was found between the NAO and the Pepper results in any of the categories. Specifically, for the Competence category, the $p - value$ was 0.63 with a $z - score$ of 0.53; in the Warmth category, the $p - value$ was 0.71 with a $z - score$ of 0.38; and in the Discomfort category, the $p - value$ was 0.54 with a $z - score$ of -0.62. Users responded positively in most categories, particularly those corresponding to competence and warmth (questions 1-6) and low for danger and awfulness (questions 9-10). However, some notable outliers exist, especially for the *capable* question. The most criticized elements were strangeness and awkwardness.

B. UTAUT Questions

Fig. 5b shows the plot for the questions taken from the UTAUT survey, organized by overarching category. As before, no significant difference was found between the robots. Particularly, in the Performance Expectation category, the $p - value$ was 0.72 with a $z - score$ of 0.36; in the Effort Expectancy category, the $p - value$ was 0.21 with a $z - score$ of 1.25; and in the Social Influence category, the $p - value$ was 0.24 with a $z - score$ of 1.17. Results corresponding to the UTAUT categories of Effort Expectancy and Social Influence were the highest. Users were most positive about



(a) Box plot for the RoSAS questionnaire data, showing from left ot right the categories: *Competence* (Reliable, Competent, Interactive, Capable), *Warmth* (Sociable, Happy), and *Discomfort* (Strange, Awkward, Dangerous, Awful).



(b) Box plot for the UTAUT answers, showing from left ot right the categories for: Performance Expectation (Codes RA1, JB5 and EM), Effort Expectancy (PEU6, EU3) and Social Influence (SN1a and SN1b).

Fig. 5. Questionnaire results.

the ease of use of the robot (PEU6) and the integrated system (EU3), as well as the perception by others of the robot (SN1a) and the overall system (SN1b).

C. *Open Questions*

In the open questions section, the most common features requested by users were to add more dialogue options (6 out of 19) and to make the movement feedback more specific and clear (4 out of 19). One participant suggested that it would be better with music and an extra screen for illustration. Two participants were satisfied with both robots and did not make any suggestions. Some participants had criticisms, suggesting that the robot should be more specific and clear when illustrating the exercise (5 out of 19) and that the on-screen feedback and interface should be improved (4 out of 19). One participant suggested simplifying the exercises instead of the robot. Specific to the Pepper robot, one participant reported that the screen attached to the robot was distracting. Regarding the NAO robot, participants noted its demonstration was less accurate compared to Pepper (3 out of 19), its postures could be odd and aggressive (2 out of 19), and its motor was noisy (1 out of 19).

D. *Physiological Data*

Fig. 6 shows the average heart rate changes for all participants. The mean heart rate during all the activities was measured to be $76.10(\pm 11.94)$ bpm for the Pepper and $77.93(\pm 10.69)$ for the NAO. No significant difference was found between the heart rate distributions. Participants showed an increase in heart rate over time, with rates rising at $0.114 bpm/second$ for exercise 1, $0.056 bpm/sec$ for exercise 2, and $0.130 bpm/sec$ for exercise 3 (slope of regression).

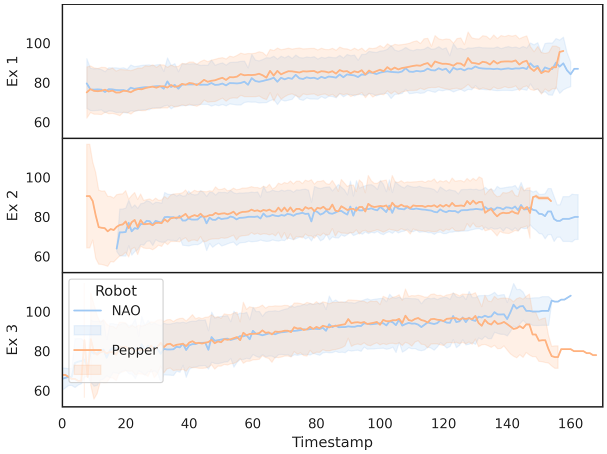


Fig. 6. Heart rate evolution for users during each of the exercises, in beats per minute. Marked intervals show one standard deviation.

IV. DISCUSSION

Regarding user performance, no significant difference was found between the interactions with the NAO and Pepper robots, with participants maintaining similar repetitions for each exercise. This consistency was also observed in instances of feedback triggered by detected mistakes. These findings suggest that the smaller form factor of the NAO robot has little effect on execution clarity, though a larger sample size is needed to confirm this. Comparing the exercise tasks, participants performed fewer repetitions for the double arm fold (Exercise 2) in the available time, consistent with having less time available.

An overall positive view of the robot's behaviour was found for the quantitative and open responses. Across both the RoSAS and UTAUT user questionnaires and their respective categories, no significant differences were found in the responses between the robots. This suggests that on an exercise application, the embodiment form factor of a robot has less effect on the participant behaviour. This contrasts sharply with the findings by [22], where the NAO was found to be more lifelike, likeable, intelligent, safe, and more socially influential than the Pepper robot. It is believed that these similarities in response may be due to participants perceiving the robot as part of a wider exercise system, and thus are less influenced by it. It could also be caused due to the different, older user sample. This should be explored in future research, exploring a wider range of robot embodiments, sizes, movement capabilities, degrees of anthropomorphism and comparison with on-screen 2D agents.

Some outliers were found in the ROSaS for the categories of capable, reliable, happy, strange and awkward. This could indicate that a few users had a strong negative reaction to the system, but a larger sample size is needed to verify this. Participants identified *Strangeness* and *Awkwardness* as the most notable drawbacks of the robots, indicating that certain elements of the interaction with both robots might cause feelings of uncanniness. As some participants attempted to interact with the robots during the trial, it is possible that the lack of voice interaction or reactivity, aside from exercise feedback, contributed to this impression. It could also be caused by the robots looking straight ahead rather than in the direction of the user. Adding some communication options or head tracking, even if only during breaks, could help reduce this issue in future iterations.

In the open questions, participants provided more negative feedback regarding the use of the NAO robot, describing it as less accurate, more aggressive-looking, and louder. This mismatch could be attributed to the interaction not being focused on the robot, as the screen-based feedback system might reduce the robot's impact and social influence. This could reinforce the view that users perceive the robot as subservient to the larger training system, similar to a display, suggesting that embodiment is less important when paired with a screen. Future experiments could evaluate other relationships between the robot, screen, and sensors. The robot could introduce the screens as part of itself, as a separate independent unit, or as an agent subservient to a wider system.

The system could offer potential applications in home environments for middle-aged and older adults through consumer-grade hardware for easy integration and setup, while providing personalized exercise routines, user-friendly interfaces, and remote monitoring capabilities. To improve interaction quality, provide better guidance, and encouragement, timely feedback is important [20]. Assessing human motion in real-time has been explored using various machine vision techniques [31]. Several of these back-ends have been explored to complement SARs, using rule-based models for exercise [20], [32] and machine learning [22], [33]. For vulnerable participants in particular, it is crucial to balance exercise intensity to prevent overexertion. To this end, direct involvement with healthcare professionals in designing the exercises, measurement criteria, and feedback is believed to have the highest impact in this area. Expanding efforts such as in Lee *et al.* [33], which utilise an expert-annotated dataset collected from trials with post-stroke patients, could be extended and made available online. This would provide a baseline for designing novel and more reactive feedback systems. Finally, a significant limitation lies in the testing population, which had an uneven gender ratio and a high level of education. This should be addressed in future work. Similarly, a larger testing population is needed to explore these observations further.

V. CONCLUSIONS

This study presented a robotic system designed to coach users through exercises while providing real-time physiological and kinematic feedback on their performance. The system monitors users' physical conditions and offers feedback during exercise sessions. The Pepper and NAO robots were compared to explore the effects of different embodiments—including physical form and size—on user responses. Nineteen middle-aged to older adults (aged 40 and above) participated in a within-subjects experiment, performing three exercises with both robots. Despite existing literature suggesting differences in user perception between these robots, the findings indicated no significant differences in user performance, perception, or physiological responses. This suggests that the embodiment form factor has a lesser impact on robotic exercise companionship , but further research with a wider robot selection is needed. Overall, users had a positive view of the robots, though some noted strangeness and awkwardness, indicating potential areas for improvement in interaction design. Further research with a larger and more diverse sample size is necessary to validate these findings and explore additional enhancements to the system. It is recommended to focus research efforts on the development of expert-annotated datasets of exercises and feedback, as well as exploring the hierarchy between the robot and the system to understand how these affect user perception.

The open-source codes of the system are available on GitHub, as addressed earlier. Additionally, a supplementary video is provided to offer deeper understanding and visual insight into the system's operation and user interactions.

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