A Comparative Study of Touch Feedback in Coaching Scenarios: Haptic Vest vs. Embodied Social Robot in Squatting Exercises

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Fig. 1. Participant performing a squat while receiving feedback from the robot and the vest

Regular exercise has numerous benefits for an individual, both physical and psychological. Therefore it is important to learn how to correctly execute physical exercise to make use of its benefits and avoid injury. Trainees can improve their execution of physical exercises based on feedback received from a coach. There have been studies on different feedback strategies to test their effectiveness on learning motor tasks. Most studies focus on rehabilitation and there is a need for more studies on the effectiveness of different feedback mechanisms in physical exercises for healthy individuals. This study focused on comparing the effectiveness of two feedback approaches on squatting exercises for healthy subjects: touch feedback from a haptic vest vs. a social robot coach. No significant differences were found in the effectiveness of improving the squatting technique between the two settings, however there are some marginal differences in the number of squats, participants' confidence and perceived system agency. Both feedback modalities were appreciated and show the importance of further analyzing haptic feedback between humans and robots.

Additional Key Words and Phrases: haptic feedback, socially assistive robots, multimodal feedback, physical exercise, human-robot interaction

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1 INTRODUCTION

Physical exercise has proven to be important for an individual to maintain a healthy life. There have been studies on a wide range of health benefits of physical exercise. To name a few examples, exercising regularly reduces cardiovascular risks [1], helps lessen aging effects [19], can enhance cognitive functions, improve overall well being and reduce depression and anxiety [12]. When talking about healthy individuals, exercising is easily accessible for most people and can be done without any materials by making use of one's own body weight. However, the accessible nature of exercising does not eradicate the need to learn how to properly execute a physical exercise to make use of its benefits while avoiding injury.

In the mission of becoming proficient in a motor task, proper augmented feedback, that is, feedback from an external source, can improve the learning process [11, 16, 24, 29]. Augmented feedback can be categorized based on the medium through which feedback is given and some of the most frequently used categories in motor learning include visual, auditory and haptic feedback. Each feedback modality has its own benefits and a multimodal feedback system can be used for a trainee to make use of all modalities concurrently and potentially increase the learning rate [24, 25]. In their literature review, Sigrist et al. [24] highlighted the benefits of these modalities and expressed the need for more studies that focus on the comparison between haptic and other feedback modalities since most studies on haptic feedback's effectiveness focused on simple motor tasks. Pedagogical touch has proven important in sports and should be considered in the study of feedback in motor learning [20].

When people need feedback on how to perform a physical exercise they can watch tutorials or have a coach help them. The latter might be a better solution since a coach can give personalized feedback. With the rise of technology, nowadays a personal coach does not need to necessarily be a human, but it could also be a robot. Humans have different needs and personality traits and it can be difficult for a trainee to find a compatible coach that matches their requirements. A socially assistive robot (SAR) on the other hand can be programmed to one's liking and in the future they might constitute the preferred feedback alternative to online or even physical coaching for many [13]. In this research, an experimental setup that allows users to receive feedback regarding their execution of a squatting exercise, one of the most common physical exercises, from different modalities was created.

Section 2 presents the motivation behind the focus of this study together with the research questions created to address the identified knowledge gap. Section 3 provides an overview of the relevant literature related to this study. Section 4 describes the system that was created to provide feedback to the participants. Section 5 explains in detail how this study was conducted. The findings of this study are presented in section 6 and discussed in section 7. Lastly, the paper ends with a conclusion in section 8.

2 PROBLEM STATEMENT

Notwithstanding that both haptic feedback and SAR as a coach have been studied, most of these studies focus on rehabilitation and people with disabilities or the elderly. There is a lack of studies that focus on how these modalities can aid healthy individuals with physical exercise. To the author's knowledge there hasn't yet been a study that compares these two modalities between each other in terms of their effectiveness in learning a physical exercise or a study involving SARs for physical training using haptic feedback. Therefore, the results of this study try to fill the gap of knowledge on the effectiveness and usefulness of these modalities for training. This study will focus on comparing the effect of two feedback modalities in squatting exercises: haptic touch through a haptic vest vs. auditory and visual feedback from a SAR.

2.1 Research Question

To address the problem statement, the following main research question arises:

What are the differences in the effectiveness of haptic feedback delivered through a haptic vest versus auditory and visual feedback from a socially assistive robot in improving squatting technique and exercise performance among healthy individuals?

To help answer the main research question, we formulate the following sub-research questions:

RQ 1) How does the immediate feedback of the haptic vest compare to the feedback provided by the social assistive robot in terms of effectiveness in correcting the execution of the squatting exercise?

RQ 2) How does the participants' perceived self and system agency change between the different exercising conditions?

RQ 3) How does the type of feedback influence subjects' motivation and physical activity enjoyment during the execution of the squatting exercise?

RQ 4) How does the participant's confidence in their ability to correctly perform the squatting exercise change between the different exercising conditions?

3 RELATED WORK

A first step in defining the scope of this research was to find relevant literature on the topic. A literature review was done to identify existing knowledge and gaps related to haptic feedback and SARs in coaching scenarios. The search engines Google Scholar and IEEE were used to find literature.

The systematic review done by Sigrist et al. [24] on visual, auditory, haptic and multimodal feedback in motor learning shed light on the need for more studies on complex tasks and more specifically for studies on the effectiveness of haptic feedback in complex motor tasks. Studies done on haptic feedback show promising results. In [22] haptic feedback was used in a gait retraining experiment for runners to reduce tibial acceleration. A wearable haptic device delivered vibrations when runner's tibial acceleration exceeded a certain threshold, signaling them to adjust their gait. The study concluded that haptic feedback in this case was as effective as other modalities, moreover less invasive and had reduced costs. [23] highlighted the benefits of using haptic feedback for both people with impairments in rehabilitation and for people without disabilities to improve execution performance and avoid injury during exercise. [9] found that haptic feedback, when used alongside verbal feedback, enhances the effectiveness of motor learning, increases perceived confidence and decreases the perceived difficulty of learning a new gymnastic parallel bars task. In this study, if participants deviated from the correct movement pattern of the motor task, a physical education teacher provided guidance to them through touch and/or vocal instructions. Haptics were also used in virtual environments: [26] showed how haptic feedback can be used to enrich people's experiences while exergaming using an exercise bike and a hand-held gamepad. Additionally, [10] found that a haptic vest improves realism and the sense of presence in a virtual environment by generating tactile and thermal stimulation while synchronizing the feedback patterns with the visual and audio stimuli of a VR system.

SARs have recently been studied in the domain of physical exercise. A SAR as a coach has proven beneficial in increasing elderly motivation and engagement during physical exercise [6, 7]. In another study, a SAR was used to aid exercise therapies for persons with dementia [5]. In [2] authors used a Pepper robot to investigate the type of feedback (negative, flattened, positive) in relation to elderly experience in physical and cognitive exercises and found that for this particular group of subjects, positive feedback was more appreciated. SARs have also been proven effective in terms of increasing motivation during physical exercise in other studies [8, 21].

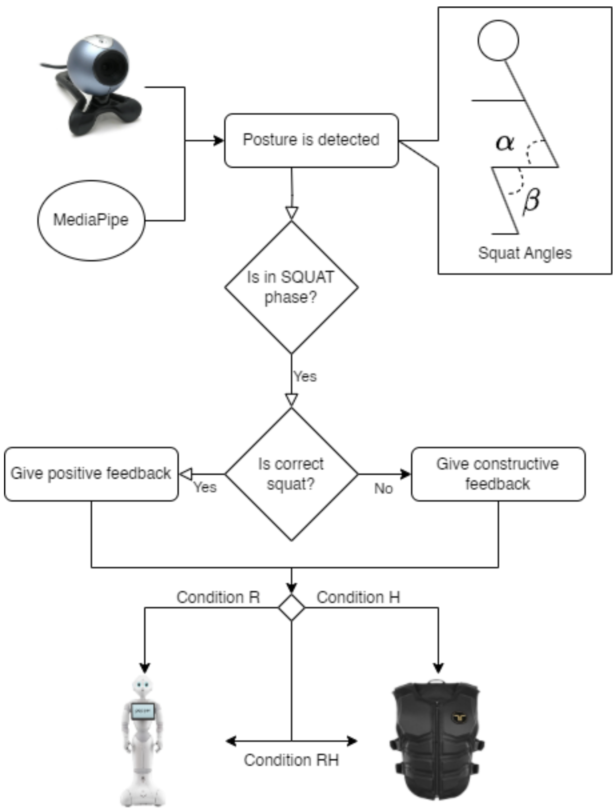

Fig. 2. Overview of the system flow

The literature review revealed that there are no studies that used haptic feedback in combination with a SAR in physical exercise training, therefore this study aims to address this knowledge gap.

4 MULTIMODAL SQUAT EXERCISE FEEDBACK SYSTEM

A bHaptics Tactsuit X40 [14] haptic vest was used to provide the user with vibrotactile feedback and a Pepper [15] social robot for auditory and visual feedback. A HD webcam was used to track participants' movements. The entire system implementation was done in Python [31] (version 2.7 for communicating with the robot and version 3.10.3 for the rest of the implementation) since both the vest and the robot offered libraries to work with in this programming language. An overview of the system can be seen in figure 2 and the explanation of each component is presented in the following subsections.

4.1 Posture Detection

A crucial part of the system was to detect the participant's movements. To achieve this, a machine learning solution for pose estimation, Media Pipe [3] was used. The input for this software was coming from the webcam recording the participant from the side for a more accurate detection of the angles formed by the shoulder-hip-knee (α) and hip-knee-ankle (β), as seen in figure 2.

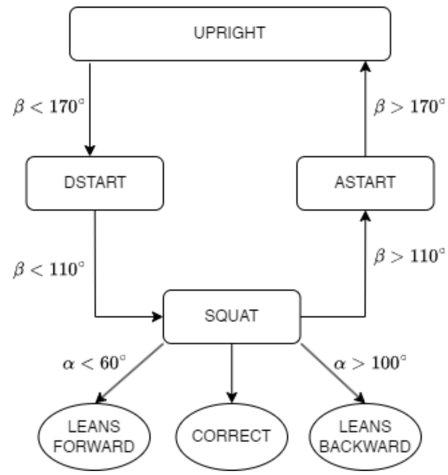

Fig. 3. The Role of α and β in Squat Analysis

4.2 Squat Definition

Defining how a correctly executed squat looks like is crucial before being able to give feedback to someone. Interestingly, there is no universally accepted definition of what a correctly executed squat is, however there are some widely accepted guidelines and standards for foot, back, hip and knee positions and for squat depth. Given the complexity and amount of parameters for executing a correct squat, a single variable on which the system gives feedback was taken, the position of the upper body in relation to the lower body. This allows the focus to be on the effect of feedback in general rather than the effect of correcting the entire squat performance. During the experiment, the participants received instructions related to the other elements of a squat:

(1) *"keep your feet shoulder-width apart"*
(2) *"keep your toes slightly pointing outwards"*
(3) *"aim to squat deep until your thighs are parallel to the ground"*

People's body proportion and mobility limitations are some of the factors that made difficult the task of defining what a proper squat for the larger population is. That is why, to leave room for diversity, the angles that define the correctness of the squat, as seen in figure 2, had a wide range in which no mistake was flagged. In this manner, when mistakes are flagged it is more likely that these are indeed mistakes and not just body-specific differences. A squat was defined as having 4 states based on the values of the knee angle β as shown in figure 3. Starting from the UPRIGHT position, a complete squat is counted when the user passes through all the states and arrives back in the UPRIGHT position. During the SQUAT phase is when the mistake detection takes place. Since the interest lies in the position of the upper body compared to the lower body, while in the SQUAT phase, the hip angle α is used to determine whether there is a mistake to correct and the type of mistake respectively.

4.3 Feedback Manager

The Feedback Manager takes care of giving the feedback to the user based on the correctness of the squat. It encapsulates both positive feedback in case of a good execution and constructive feedback when a mistake happens. It also makes sure that feedback is not given too often so that participants have time to process it. Participants were instructed to perform the squats slowly and take around 3-4 seconds per squat execution. The Feedback Manager was configured with a minimum of 3 seconds of delay between feedback actions. Besides this delay, an average moving window of 10 frames was used to asses the correction of the squat. If no mistake was detected in any of the window's frames, positive feedback was given. Alternatively, if a mistake is detected and more than 3 seconds have passed since the last feedback, constructive feedback is given based on which mistake is (predominantly) present. The feedback is given only in the SQUAT phase, since that is where the execution is verified for correctness. The last functionality of the Feedback Manager is to manage the output modalities. Different experimental conditions require different outputs for the feedback to get to the user: haptic vest + vocal from speaker, robot, vest + robot.

4.4 Haptic Modality

The vest had two types of feedback representative to the two possible mistakes: leaning forward or backward. No feedback was given through the vest when the execution was correct. The feedback from the vest was a wave-like vibration starting from the bottom of the vest and going up towards the neck using 100% intensity either in the front or in the back. When leaning forward the vibration was in the front suggesting that the person should raise their upper body, and when leaning backward the vibration was in the back respectively. This vibration pattern was chosen after the pilot study and by trying multiple possible patterns, this one being considered the most intuitive by the participants of the pilot study. The haptic feedback was also accompanied by vocal feedback. Google's Text-to-Speech API [28] was used to create audio files which were played based on the feedback type. The feedback was short and unpretentious as can be seen in table 1, and the same phrase didn't repeat itself successively.

4.5 Robot Modality

During the experiment the robot was placed in front of the participant. Just like the vocal feedback used in the haptic modality, the robot used certain phrases for the type of feedback, as shown in table 1. The phrases used by the robot were changed slightly to avoid repetition but the message was the same.

Furthermore, at the beginning of the condition R the robot introduced itself with the phrase: *"Hello {participant}! I am Pepper. I am here to help you with your squats. When you're ready start squatting and I will join you!"*. At the beginning of the condition RH, the phrase *"Hi again {participant}! I am excited to work out with you once more! When you're ready, start squatting and I will join you!"*. At the end of both these conditions, the robot ended the squatting session with the phrase *"You did a great job today {participant}! I enjoyed working out with you!"*.

Beside the verbal feedback, the robot also provided visual feedback to the participant. The robot was squatting together with the participant. When the participant was in the descending phase, the robot also started to descend into the squat position, and went back

Table 1. Verbal Phrases Used For Feedback

Actor	Squat Correctness	Phrase
Speaker	Correct	*"keep it up"* *"nicely done"* *"good job"* *"you can do it"* *"awesome"*
	Leans Forward	*"raise your torso"* *"straighten your back"* *"keep your chest a bit higher"*
	Leans Backward	*"lean your torso a bit forward"* *"bring your chest a bit lower"* *"lean forward a bit"*
Robot	Correct	*"first squat looks great"* *"you're doing great"* *"it's looking good"* *"you're improving"* *"you're getting good at this"* *"nice work"*
	Leans Forward	*"raise your torso a bit"* *"keep your back straight"* *"you're leaning a bit forward"*
	Leans Backward	*"bring your upper body a bit lower"* *"could you try to lean your torso a bit more?"* *"lean forward a bit more"*

to the upright position when the participant started to ascend respectively. As can be seen in figure 4, the angle θ of the robot's hip pitch was used to change the robot's posture and provide visual feedback based on the participant's execution. The robot always descended in the position for a correct squat for the participant to notice the changes in θ in case of a mistake.

5 METHODOLOGY

This section describes detailed explanation of the research methods used in this study from scoping the research to drawing conclusions.

5.1 Experimental Design

Answering the research questions of this study requires multiple experimental conditions: exercising with the vest, with the robot and with both together.

To account for individual physical fitness, allowing the comparison of the within-subject differences between the conditions without the need to add even a further baseline condition that would be required for computing differences between the baseline and conditions, a within-subjects design was used. To compare the differences between the conditions, a specific physical exercise that is to repeat in every condition needed to be chosen. There are countless physical exercises to choose from, but for this study the squatting exercise

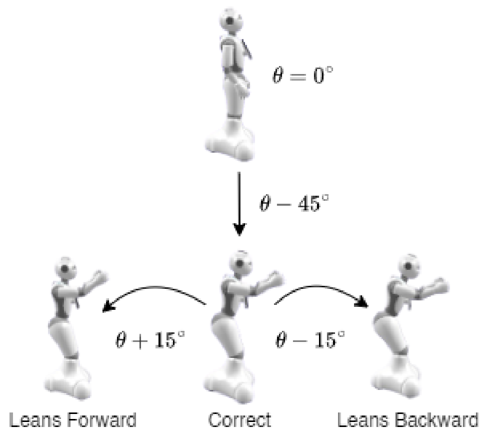

Fig. 4. Robot's Hip Pitch Changes Based On Participant's Execution

was chosen since it is one of the most commonly known exercises in the gym or used in bodyweight training.

This study was approved by the Ethics Committee Computer & Information Science (EC-CIS).

5.2 Participants

In this study, 10 participants, 4 female and 6 male, were gathered for the experiment by asking other students in the university to participate. The mean age of the participants was *M*=21.5 with a standard deviation *SD*=0.76. In terms of their experience in working with technology, 1 participant had some experience, 6 participants had good experience and 3 participants had extensive experience. Their skill level in performing a squatting exercise is as follows: 1 participant with little experience, 2 participants have some experience, 4 have good experience and 3 stated that they have extensive experience.

5.3 Study Procedure

To avoid bias, before the experiment participants were only informed that they need to perform some squats and that they will receive feedback based on the correctness of their execution in different exercising conditions, but they did not know which or how many different conditions they will experience. Not disclosing this information was necessary for measuring motivation since participants may decide to conserve energy in certain settings because they know there are other conditions left for them to exercise in. Furthermore, the following counterbalancing technique was used to enforce bias avoidance: participants with an odd number started with condition H (receiving feedback from the haptic vest), while participants with an even number started with condition R (receiving feedback from the robot).

Since the main focus of this study is to check the differences of effectiveness in correcting squats between the feedback delivered through the vest vs. the robot, the condition in which participants will receive the feedback from both these modalities will be experienced last. In this way an analysis between just the vest and the robot can be done without introducing bias by exposing both conditions to the participants in the beginning. Before each condition, the participants were asked to do as many squats as they would like. They were told that the condition would be finished when they say they are done. The participants were asked to answer a questionnaire after each condition. All participants gave their written consent before the experiment.

5.4 Data Gathering

Both quantitative and qualitative data was gathered. Quantitative data gathered in this study are: the number of squats, the number of mistakes, the highest streak of correct squats in a condition, age, technology skill level, squat skill level and questionnaire responses using a 5-point Likert scale aimed at evaluating the participant's perceived confidence, exertion [18], physical activity enjoyment [4], self agency [27], system agency [30] and haptic experience. Qualitative data were gathered through an optional open-ended question at the end of the questionnaire where participants could write any closing thoughts and through observations during the participants' execution.

5.5 Data analysis

The analysis was done in a Jupyter Notebook [17], using Python version 3.10.3. A performance score for each participant in each condition was created to measure the effectiveness in correcting the squats. To calculate the score for a given condition the following formula was used:

$$\text{Score}_\text{c} = T_\text{c} - M_\text{c} + S_\text{c} \tag{1}$$

where:

- Score_c is the score for a specific condition c.
- T_c is the total number of squats performed in c.
- M_c is the number of mistakes made in c.
- S_c is the value of the highest streak of successful squats in c.
- $c \in C$ where C is the set of all conditions in which participants performed the squatting exercise.

In the context of this study:

- $C = \{H, R, RH\}$ where H (Haptic feedback), R (Robot feedback), and RH (Combined Haptic and Robot feedback).

Furthermore, the final score for each participant is defined by:

$$\text{Score} = \frac{1}{|C|} \sum_{i \in C} \text{Score}_i \tag{2}$$

where:

- Score is the average score across all conditions.
- Score_i is the score for condition i.
- $i \in C$ indicates that the sum is taken over the conditions in set C.
- $|C|$ denotes the number of conditions in set C.

6 RESULTS

The purpose of this study was to identify the differences in the effectiveness of haptic feedback delivered through a haptic vest versus auditory and visual feedback from a socially assistive robot

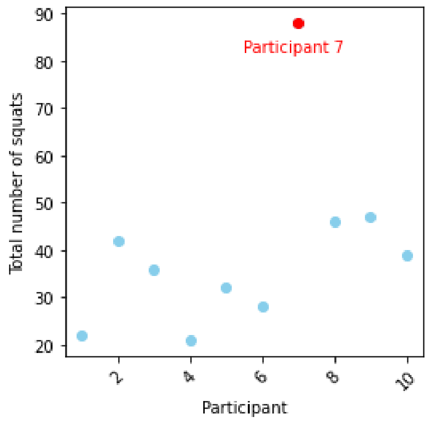

Fig. 5. Participant 7 Exclusion

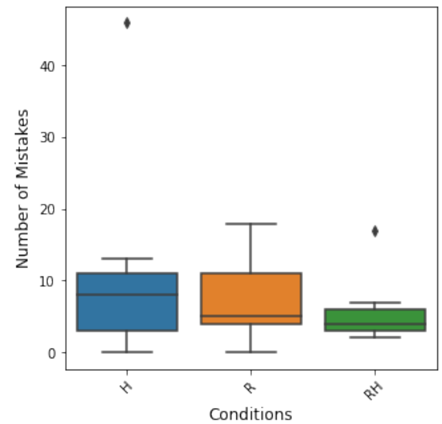

Fig. 6. Number of Mistakes Between Conditions

in improving squatting technique and exercise performance among healthy individuals. The data from one participant was excluded from the analysis because this participant did not adhere to the instruction to take between 3-4 seconds per squat execution and consequently the number of squats done by this participant was far bigger than the rest (mean of the total number of squats without participant 7 is 34.7, and the number of squats done by participant 7 is 88) as can be seen in figure 5.

The normality of the data was determined using the Shapiro-Wilk test for normality and the equality of variances was decided by Levene's test for equality of variances. To check for statistically significant differences between the conditions H and R, the Paired Samples t Test (t statistic) and the Wilcoxon Signed-Rank Test (W statistic) were used. The differences between all three conditions were determined by the Repeated Measures ANOVA (F statistic) and the Kruskal-Wallis test (H statistic). The level of significance for all tests was α=0.05.

Table 2 presents an overview of the mean and standard deviation values for all variables in this study according to the condition in which they were measured.

Figure 6 illustrates the difference in the number of mistakes done by the participants between the three conditions. Both H and R have an outlier, but the value of the one in H (46) is greater than the one in R (17), therefore increasing the mean value of mistakes.

6.1 Quantitative Data

Table 3 shows all the statistical results for the comparison between H and R. There were no significant differences except for two marginal significances on the number of squats and perceived system agency. The number of squats was marginally different between H (M=13.00, SD=5.68) and R (M=10.11, SD=3.10). Perceived system agency was also marginally different between H (M=3.48, SD=0.67) and R (M=3.81, SD=0.61).

As shown in table 4, the results for the comparison between all three conditions reveal no significant differences except for a marginal significance on the participants' confidence. Their confidence at the beginning of the experiment, before experiencing any conditions, in $T0$ (M=6.83, SD=1.35) was marginally different from their confidence in condition RH (M=8.39, SD=0.78).

Participants appreciation of the haptic experience was also analyzed on a 5 point Likert scale. Their responses were on the positive side towards the usefulness of the haptic feedback with a mean value of 3.93 (SD=0.76). The minimum value was 2.67 and the maximum was 5.00 respectively.

Three questions were present in the questionnaire with the aim of finding out whether people think that the system, the robot or the vest was guiding them through touch. The responses to the question about the system (M=3.22, SD=0.83) and the vest (M=4.11, SD=0.78) differed significantly according to the Wilcoxon signed-rank test (W=0.00, p=0.02).

The calculation of the Spearman's correlations of perceived self and system agency between different conditions was performed. Participant's perceived system agency between R and RH was strong and significant (r_s=0.84, p=0.004). Between H and RH (r_s=0.19, p=0.63) and H and R (r_s=0.44, p=0.24) there was no significant correlation. Furthermore, participant's perceived self agency has a strong and significant correlation between H and RH (r_s=0.87, p=0.002), but no significant correlation between H and R (r_s=0.60, p=0.09) and R and RH (r_s=0.61, p=0.08).

6.2 Qualitative Data

Four participants expressed positive thoughts towards the haptic feedback received from the vest. Participant 1 stated: *"the pressure from the vest felt good, like a squatting belt which I usually use"*. This participant also has the highest rated haptic experience with a value of 5. Both participants 5 and 6 liked the vest and thought it was useful in correcting exercise execution. Participant 10 said he was surprised by the vibrations of the vest the first time they encountered it. He didn't understand what the vibrations meant until he heard the vocal feedback as well, but after he understood what the vibrations were telling him, he liked the feedback and said he would see real applications for it in a gym training scenario. Two participants expressed negative feelings towards the robot.

Variable	H (Mean ± SD)	R (Mean ± SD)	RH (Mean ± SD)	Variable	Mean ± SD
Confidence	7.50 ± 2.52	7.56 ± 1.10	8.39 ± 0.78	Confidence T0	6.83 ± 1.35
Highest Streaks	4.22 ± 2.99	4.00 ± 2.45	4.67 ± 2.65	Final Highest Streak	5.78 ± 2.11
Number of Mistakes	11.11 ± 13.75	7.22 ± 5.61	5.44 ± 4.61	Final Score	7.89 ± 7.42
Number of Squats	13.00 ± 5.68	10.11 ± 3.10	11.67 ± 3.12	Haptic Experience	3.93 ± 0.76
PA Enjoyment	3.92 ± 0.72	3.97 ± 0.96	3.83 ± 0.91	Robot Guiding Me Through Touch	2.67 ± 1.66
Perceived Exertion	3.33 ± 1.50	2.56 ± 1.33	3.11 ± 0.93	System Guiding Me Through Touch	3.22 ± 0.83
Perceived Self Agency	3.85 ± 0.70	4.01 ± 0.50	3.88 ± 0.68	Vest Guiding Me Through Touch	4.11 ± 0.78
Perceived System Agency	3.48 ± 0.67	3.81 ± 0.61	3.76 ± 0.74		
Score	6.11 ± 12.83	6.89 ± 7.27	10.89 ± 5.90		

Table 2. Mean and Standard Deviation of Variables

Table 3. Comparisons Between Condition H and R

Variable	Statistic	p-value
Confidence	W=10.50	1.00
Highest Streaks	t(8)=0.32	0.76
Number of Mistakes	W=9.50	0.23
Number of Squats	t(8)=2.14	0.06
PA Enjoyment	t(8)=-0.18	0.86
Perceived Exertion	t(8)=1.67	0.13
Perceived Self Agency	W=12.00	0.25
Perceived System Agency	t(8)=-2.16	0.06
Score	W=21.00	0.91

Table 4. Comparisons Between All Conditions

Variable	Statistic	p-value
Confidence (T0 to T4)	$H(2) = 7.23$	0.06
Highest Streaks	$F(2, 16) = 0.30$	0.75
Number of Mistakes	$H(2) = 1.63$	0.44
Number of Squats	$F(2, 16) = 1.86$	0.19
PA Enjoyment	$H(2) = 0.54$	0.76
Perceived Exertion	$F(2, 16) = 1.86$	0.19
Perceived Self Agency	$H(2) = 0.08$	0.96
Perceived System Agency	$H(2) = 2.60$	0.27
Score	$H(2) = 1.06$	0.59

Participant 1 mentioned he didn't like that he had to wait for the robot to be upright as well. Likewise, participant 2 said he dislike the fact that *"the robot was not moving in sync"*. In contrast, participants 3, 8 and 9 liked working with the robot. Participant 3 thought the robot was *"cute"* and *"fun to exercise with"*. Participant 8 felt the need to talk to the robot while squatting. She used the phrase *"just for you I will do two more repetitions"* and she thanked the robot when it was praising her for a correct repetition. Participant 9 stated: *"The voice that the robot had and the attitude felt way more human and it helped me in improving the way in which i was doing squats. The voice that was giving feedback only with the vest sounded a bit too unfamiliar and did not give me the impression that i want to work with it again"*.

7 DISCUSSION

This study aimed to find the differences in the effectiveness of haptic feedback given from a haptic vest and the feedback received from a SAR in improving the squatting technique among healthy individuals. The findings of this study suggest that there are no significant differences between the two feedback conditions.

7.1 Answers to Research Questions

7.1.1 RQ 1. For each participant a score was calculated corresponding to their performance in each of the conditions. The comparison of their scores between conditions did not show any significant difference and therefore, from the quantitative data it can't be said that one feedback modality might be better than the other in terms of effectiveness in correcting the execution of the squatting exercise.

The outlier in H increased the mean value of mistakes in this setting, however the data comes from a participant that listened to the instructions given before the experiment and therefore it was not removed. This participant encountered condition H first and each repetition had the same mistake, leaning too much forward. She didn't seem to be able to complete a correct squat in this condition, but she improved afterwards, making 1 correct squat in R and 6 in RH. Both the learning effect and the combination of the modalities are possible explanations for her performance improvement.

Furthermore, four participants expressed their positive feelings towards the haptic feedback from the vest and the overall appreciation of the haptic experience was on the positive side (M=3.93, SD=0.76). Two participants expressed negative feelings towards the feedback received from the robot while the vest did not receive any negative reviews.

7.1.2 RQ 2. Although no significant differences were found in the participants' perceived self agency between the exercising conditions, a marginal difference was found in their perceived system agency between H and R (p=0.06). Additionally, some significant correlations were found between the exercising conditions. Participants' perceived system agency was high between R and RH (r_s=0.84, p=0.004) and perceived self agency was high between H and RH (r_s=0.87, p=0.002). These correlations imply that the robot plays an important role in the way participants perceive the agency of the system. Additionally, the haptic feedback provided by the vest does have an impact on the participants' perception that they are in control.

7.1.3 RQ 3. Neither the participants' perceived exertion or physical activity enjoyment showed a significant difference between the conditions. The number of squats showed a marginally significant difference (p=0.06) between H (M=13.00, SD=5.68) and R (M=10.11, SD=3.10). As previous research indicated that a SAR increases motivation in physical exercise [6, 7, 8, 21], condition R was expected to at least produce a higher number of squats, which was not the case in this study. The haptic feedback from the vest could have had a positive impact as well on the participant's motivation and this could be a reason why no significant difference between the two modalities was found.

7.1.4 RQ 4. No significant differences were found between the four moments in which participants' confidence in their ability to correctly perform squats were found, however the p-value 0.06 was very close to the significance level. The learning effect needs to be considered since the highest difference was between the moment before starting the experiment and the moment after experiencing all conditions and the participants may have become more confident due to practice. However, the literature review revealed that haptic feedback when used alongside verbal feedback increases confidence in the context of learning a new physical exercise [9], and therefore the small sample size of this study could have been a limiting factor in finding a more significant difference.

7.1.5 Main RQ.. The answers to the previous questions revealed that there aren't any significant differences in the effectiveness of haptic feedback delivered through a haptic vest vs. auditory and visual feedback from a SAR in improving squatting technique and exercise performance among healthy individuals. However, some marginal differences were found in the number of squats, participants' confidence and perceived system agency which could have been limited by the small sample size of this study.

Previous research suggested that both haptic feedback and feedback from a SAR can be effective in improving physical exercise [6, 7, 8, 9, 10, 21, 22, 23], however this is the first study to combine the two modalities.

7.2 Limitations and Future Work

First of all the small sample size is a limiting factor. Only 10 participants were gathered and the data collected from one participant was excluded from the analysis. Most people in this study had good or extensive experience both with technology and squats, only one person stated that they lave little experience with squats. A bigger and more diverse sample size could reveal better insights. A longer time frame would allow for more complex and fine-tuned implementations of the feedback modalities.

The feedback from the vest was a limiting factor to the amount of feedback that can be given through this modality. The vest can only give feedback in the torso and therefore this study was limited to the feedback that focused on the angles formed by the upper body in relation to the lower body. A squat is however a complex exercise that has many other guidelines for a correct execution (foot, back, hip and knee positions and squat depth). These guidelines were explained to the participants at the beginning of the study but for a better comparison of the feedback modalities, the feedback could be more complex and accounting for all these guidelines. Given the exercise complexity, a correct squat can differ from one participant to another based on their body proportions. A large range was taken for the expected values of the angles formed in a correct squat, however a better model for correcting the squat execution would need to account for different body proportions.

Taking into account the insights gathered from previous studies that show the potential of haptic feedback and feedback from a SAR in improving physical exercise efficiency, and the results and limitations of this study, more research is needed to better understand the effect of this two modalities, both individually and combined.

8 CONCLUSION

To the author's knowledge, this is the first study to investigate the combination of haptic feedback in bodyweight training accompanied by a SAR. A multimodal feedback system for correcting the squatting exercise was created for the participants to experience each feedback modality individually and a combination of both.

The results might not show any significant differences between the two feedback modalities, but can guide future research. Additionally, the results reveal that there is a significant potential of further using and exploring haptic feedback between humans and robots in exercising scenarios whether they are mediated or part of physical human-robot interaction.

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