Improving Rehabilitation Exercise Performance through Visual Guidance

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Abstract— **In current physical rehabilitation protocols, patients typically perform exercises without feedback or guidance following the initial demonstrations from the physiotherapist. This paper proposes a system providing continuous visual feedback and guidance to patients to improve quality of motion performance and adherence to instructions. The system consists of body-worn inertial measurement units which continuously measure the patient's pose. The measured pose is overlaid with the instructed motion on a visual display shown to the user during exercise performance. Two user studies were conducted with healthy participants to evaluate the usability of the visual guidance tool. Motion data was collected by the inertial measurement sensors and used to evaluate quality of motion, comparing user performance with and without visual feedback and with or without exercise guidance. The quantitative and qualitative results of the studies confirm that performing the exercises with the visual guidance tool promotes more consistent exercise performance and proper technique.**

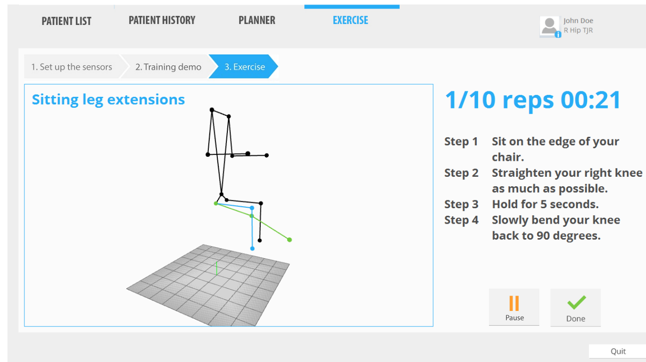

Fig. 1. A screen shot of the ARS visualization tool. The green leg is the EGF motion and the blue leg is the visualization of the user's real-time motion.

I. INTRODUCTION

In physical rehabilitation, patients who perform rehabilitation exercises under the supervision of a physiotherapist (PT) perform the exercises more correctly and have less pain compared to patients who learn and complete the exercises from a brochure [1]. Although there are benefits to direct supervision from PTs while patients complete the exercises, PTs are usually supervising multiple patients during the same exercise session in the clinical setting. As a result, patients are not given constant feedback on the correctness of their exercise performance.

In the existing literature, various systems have been developed to provide feedback regarding motion quality. PT Viz [2] uses bend sensors to detect the bend angle of the knee and gives visual notification of the bend progression as the patient performs knee extensions. TactaPack [3] uses an accelerometer sensor system to detect the movements of the limb as a user is exercising. If the sensors detect an unsafe position, the system notifies the user through haptic feedback. While both these systems provide feedback when the motion is incorrect, they do not provide guidance for proper form.

Research groups have considered using the concept of gamification to encourage patients to preform repetitive exercise motions. RIABLO [4] utilizes five inertial sensors and a board of pressure sensors to capture the movement of the patient; users collect rewards by preforming the exercise movements in games designed for RIABLO. Uzor and Bailie's system [5] also uses inertial sensors to track motion and have developed games to be played in the home setting to encourage seniors to perform their exercises. While these systems are excellent for encouraging patients to perform multiple repetitions of exercises, a new game has to be designed and implemented for new exercise motions. Users are also expected to have prior knowledge of the exercise motion before playing the game, which would not be suitable for patients who are new to rehabilitation and just starting to learn the exercise motions.

The Automated Rehabilitation System (ARS) is a project under development by the Adaptive Systems Laboratory at the University of Waterloo. The system is targeted for clinical use in physical therapy for both physiotherapists (PTs) and physiotherapy patients. Patients wear SHIMMER [6] inertial measurement unit (IMU) sensors which track their movement as they perform rehabilitation exercises. The system takes accelerometer and gyroscope data from the IMUs and converts it to joint angles using a pose estimation algorithm [7], and also segments the time series data of the exercises online using a segmentation algorithm [8]. In this work, we propose a visualization tool which guides the patients in performing the correct motion while also displaying information about their exercise session, such as counting the number of repetitions (REPS) completed. Fig. 1 is a screen shot of the visualization tool. The exercise guidance feature (EGF) of the visualization tool provides continuous visual feedback to the user with regards to the ideal exercise motion, in comparison to their current motion. This paper analyses the exercise performance of users while using EGF and evaluates the usability of EGF.

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II. EXERCISE GUIDANCE FEATURE

The IMUs of ARS capture the exercise movements and the system computes the leg pose; the leg positions are then rendered on a virtual avatar in real-time. EGF provides real-time guidance and aids users in recalling the exercise by rendering the first half of the ideal exercise motion overlaid on the user's real-time motion in the visualization tool. The system monitors user progress and adjusts the advancement of the guidance accordingly. When the system detects that the patient has performed the motion and achieved the final flexion or extension position, the visualization tool will render the second half of the motion, returning to rest position. The patient follows the guiding motion for each portion of the exercise (flexion and extension).

The exemplar motion of EGF can be recorded by a PT to ensure that the correct motion is rendered in the visualization tool and followed by the patient. This also allows PTs to create exemplar motions for new exercise motions or customize the motion of existing exercises.

III. USER STUDIES

Two user studies were conducted to evaluate the usability of EGF with healthy participants. The first study compared the visualization component alone to the combined visualization and guidance system, while the second study compared the complete user interface (UI) of ARS with a typical current clinical protocol. In current practice, patients are provided with a log sheet listing the exercises and number of REPS to be performed. In both studies, participants were asked to perform two sets of exercises under two test conditions while their motion was recorded using the IMUs of ARS. Before the participant performed each exercise, the exercise was demonstrated once by one of the researchers. Upon completion of the exercises, the participants were asked to complete a questionnaire with regards to the perceived usability of the various test conditions. After completing the questionnaire, the researchers conducted a semi-structured interview with the participants, where they were asked to elaborate on their answers from the questionnaire. Both studies were approved by the University of Waterloo Ethics Board.

A. User Study #1

Participants were required to complete two sets of two leg exercises with the right leg: sitting leg extension (SIT KNEE EX) and standing hip extension (STAND HIP EX). The SIT KNEE EX exercise required participants to sit on a chair, straighten the knee until the leg was parallel to the ground, and then return the leg to starting position. The STAND HIP EX exercise required participants to stand upright, bring their leg back while keeping the knee straight, and then return the leg to starting position. The participants were asked to complete one set of 10 REPS of each exercise using EGF, and the other set of 10 REPS of each exercise while watching their real-time motion in the UI but with the EGF turned off. Participants in Group A performed the exercises first without (WO) EGF, and then with (W) EGF; participants in Group B performed the exercises in the reverse order. The researchers did not specify how the EGF should be used. Some participants waited to watch the motion of the guide leg before attempting the motion. Others chose to "chase" the motion, copying the motion of the guide leg as it was moving.

B. User Study #2

Participants were required to complete two sets of three leg exercises with the right leg: SIT KNEE EX, standing knee flexion (STAND KNEE FLEX) and standing hip flexion (STAND HIP FLEX). The STAND KNEE FLEX exercise required participants to stand upright, bend the knee until the leg is at about a 90° angle, and then straighten the knee, returning to starting position. The STAND HIP FLEX exercise required participants to stand upright, bring their leg forward while keeping the knee straight, and then return the leg to starting position. The participants were asked to complete one set of 10 REPS of each exercise using the log sheet as reference, and the other set of 10 REPS of each exercise using EGF along with the UI of the system. Participants in Group A performed the exercises first with the log sheet, and then with EGF, while participants in Group B performed the exercises in the reverse order. While using EGF, participants were asked to wait for the guide leg motion to complete before executing the motion. This is due to the fact that during study #1, participants who did not wait for the motion to complete and instead performed the motion simultaneously with the guide leg were more likely to find using the EGF confusing.

C. Hypotheses

The expected results of the studies are summarized into the following hypotheses: H1: EGF will improve the consistency of exercise performance and lower the variability between participants, H2: EGF will improve correctness of the range of motion in exercise performance and H3: Participants will prefer the UI and EGF to the log sheet or the UI WO EGF.

IV. ANALYSES AND RESULTS

Study #1 was conducted with 12 participants [N=12; M= 24.8 years old; SD=5.25 years]. There were six females and six males in the study. Study #2 was conducted with 10 participants [N=10; M=24.1 years old; SD=3.07 years]. There were six females and four males in the study. All participants either never had a prior injury that impaired mobility or have fully recovered from their injury. Participants were not repeated between studies. One participant from Group A and two participants from Group B in study #1 were removed from the quantitative results due to measurement errors.

The quantitative data is grouped into four conditions: Group A performing the exercises first WO EGF then W EGF and Group B performing the exercises first W EGF then WO EGF. Table I and II summarizes the mean and standard deviation (SD) for each of the maximum (MAX) and minimum (MIN) angle features of the corresponding moving joint for each exercise performed by the participants

TABLE I
THE MEAN MAXIMUM AND MINIMUM ACTIVE JOINT ANGLES FOR USER STUDY #1

	Group A		Group B	
	WO EGF Mean (SD)	*W EGF Mean (SD)*	*W EGF Mean (SD)*	*WO EGF Mean (SD)*
SIT KNEE EX MAX Pos (°)	3.00 (5.26)	-0.02 (5.07)	-0.87 (6.25)	0.64 (6.43)
SIT KNEE EX MIN Pos (°)	-77.16 (7.62)	-99.65 (5.35)	-102.98 (3.24)	-103.73 (3.00)
STAND HIP EX MAX Pos (°)	-3.54 (10.96)	7.44 (3.94)	10.02 (3.28)	7.98 (9.37)
STAND HIP EX MIN Pos (°)	-71.70 (21.21)	-58.06 (9.14)	-54.41 (13.37)	-66.41 (14.55)

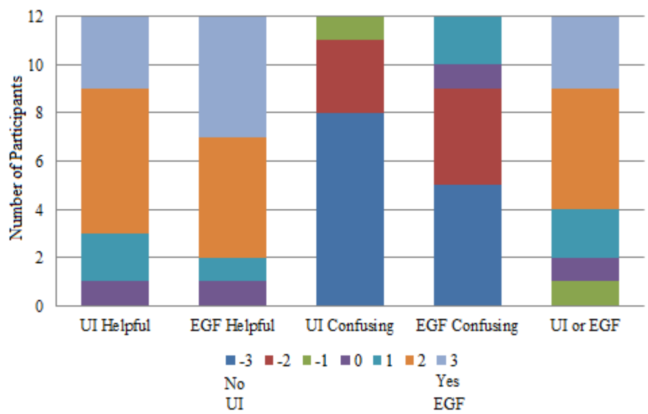

Fig. 2. Questionnaire results from user study #1. Participants answered questions with regards to the perceived helpfulness and confusion of the user interface without the exercise guidance feature (UI) and the user interface with the exercise guidance feature (EGF). Participants were also asked if they preferred UI or EGF.

TABLE II
THE MEAN MAXIMUM AND MINIMUM ACTIVE JOINT ANGLES FOR USER STUDY #2

	Group 1		Group 2	
	WO EGF Mean (SD)	*W EGF Mean (SD)*	*W EGF Mean (SD)*	*WO EGF Mean (SD)*
SIT KNEE EX MAX Pos (°)	-1.30 (10.59)	-7.51 (3.07)	-0.09 (5.42)	2.70 (4.36)
SIT KNEE EX MIN Pos (°)	-76.20 (14.71)	-96.28 (6.98)	-96.37 (6.20)	-81.76 (13.64)
STAND KNEE FLEX MAX Pos (°)	-8.61 (14.82)	-2.90 (9.45)	3.81 (4.61)	-3.90 (5.81)
STAND KNEE FLEX MIN Pos (°)	-104.35 (12.83)	-103.62 (6.33)	-95.30 (5.70)	-97.28 (5.97)
STAND HIP FLEX MAX Pos (°)	78.00 (15.83)	49.61 (12.77)	48.75 (12.39)	60.37 (11.84)
STAND HIP FLEX MIN Pos (°)	4.06 (15.02)	-7.98 (5.26)	-11.02 (5.64)	-10.28 (4.77)

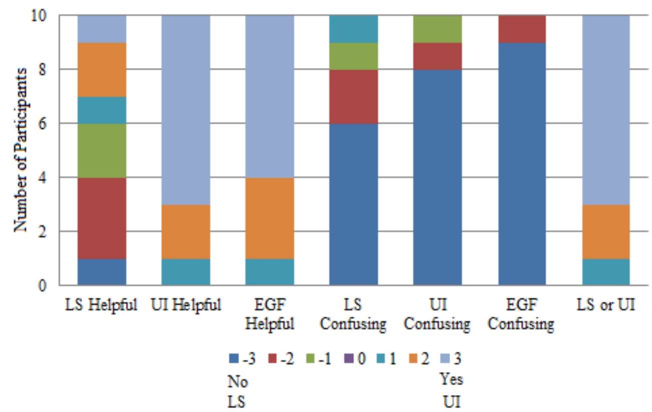

Fig. 3. Questionnaire results from user study #2. Participants answered questions with regards to the perceived helpfulness and confusion of the log sheet (LS), overall user interface with the exercise guidance feature (UI) and the exercise guidance feature (EGF). Participants were also asked if they preferred LS or UI.

for study #1 and #2, respectively. All angles are referenced from the position where the leg is straight, in the standing position. Participants were expected to go from a MAX of -10° to a MIN of -90° for SIT KNEE EX and STAND KNEE FLEX, 0° to -25° for STAND HIP EX and 25° to 0° for STAND HIP FLEX. Within each group and between conditions, the Levene's test was performed on the variance of each feature at a significance of $p < 0.05$ and independent t-tests, assuming unequal variance, were conducted on the error between the desired and achieved MAX and MIN angles at a significance of $p < 0.05$. The results from the questionnaire are summarized in Fig. 2 and 3 for study #1 and #2, respectively.

A. User Study #1

The Levene's test revealed that the null hypothesis (SDs are equal between conditions) is rejected for every feature with the exception of SIT KNEE EX MAX for Group A and the MIN angles for Group B. The independent t-tests revealed that the null hypothesis (target range of motion errors are equal between conditions) is rejected for every feature in Group A and the null hypothesis failed to be rejected for every feature except STAND HIP EX MIN for Group B.

Most users found the UI and EGF helpful, and did not find the UI or EGF confusing. During the interviews, one of the questions asked was whether participants would continue using EGF after they already learned the exercise motion. Most of the participants mentioned that they preferred to use EGF even after learning the exercise. PX3 and PX7 identified that EGF encourages proper range of motion. PX3 expressed that "Keeping the guidance feature on is better for me to know that I reached the right angle every rep," and PX7 said "...It helps to have a reference point so I know when to stop." PX8 and PX12 identified that there was a motivation component to EGF. PX8 said "Tracking something you see is more encouraging," and PX12 had expressed that "I like having the companion there to do the exercise with me, even if it's just an imaginary leg."

B. User Study #2

The Levene's test revealed that the null hypothesis is rejected for every feature with the exception of STAND HIP FLEX MAX for Group A and the null hypothesis failed to be rejected for every feature except SIT KNEE EX MIN for Group B. The independent t-tests revealed that the null hypothesis is rejected for every feature with the exception of SIT KNEE EX MIN and the STAND KNEE FLEX angles for Group A, and the MIN angles for Group B.

Users generally preferred the proposed system to the log sheet. During the interviews, two participants directly compared the log sheet and the UI, and expressed their preference for the UI over the log sheet. PX1 said "I can just watch the system to learn but you have to explain the sheet to me," and PX8 stated that "When using the log sheet, I might get lazy and do the exercise inconsistently, but using the system, I focus on doing it properly." Many of the participants also saw the benefits of using the EGF and comparing their motion to the guide leg. PX2 said "I don't like reaching the mark and waiting but the guide leg reminds you how far to go," and PX5 explained "In small steps, you can see how to move your leg up and then how to move your leg down." Some had mentioned that they would continue using the UI and EGF when exercising in the long term. PX9 had said "I would use the both the guide leg and software in the long term to encourage proper timing and movement," and PX10 said "(I would) use both the system and guide leg in the long term because you don't want to develop bad habits, the system reminds you what to do correctly."

V. DISCUSSION

The quantitative results show evidence to support H1 and H2 and the qualitative results show that H3 held true.

The results of the Levene's tests, Table I and II support H1, especially with Group A. For each feature in which the variance is significantly different, the SD is greater in the WO EGF condition in comparison to the W EGF condition. This is seen in 8/10 features of Group A and 3/10 features of Group B. The results show that consistency improved when participants were first exposed to visualization and guidance.

The results of independent t-tests, Table I and II support H2. With the exception of Group A STAND HIP EX MAX in study #1 and Group A SIT KNEE EX MAX and STAND HIP FLEX MIN in study #2, for all the features which are significantly different, the error value is greater in the WO EGF condition in comparison to the W EGF condition. This is seen in 4/10 features of Group A and 4/10 features of Group B. In 3/10 features of Group A, the values are significantly different and the error values are greater in the W EGF condition, and in 3/10 features of Group A and 6/10 features of Group B, the values were not significantly different. The results show that participants were over-extending significantly more in STAND HIP EX and over-flexing significantly more in STAND HIP FLEX without the help of guidance. This can be confirmed from the researcher's observations as some participants interpreted the exercise as having to extend or flex as far as possible, and achieved this by kicking their leg or bending their torso to compensate.

Fig. 2 and 3 shows support for H3. All participants' answers in study #2 and all but two participants' answers in study #1 are in the 1 to 3 range in favour of using EGF over the alternative. H3 is further supported in the answers with regards to the perceived helpfulness and reduced confusion of the various systems. All participants but one in study #1 found the UI and EGF helpful in learning the exercise. Similarly, all participants in study #2 found the UI and EGF helpful in learning the exercise. Participants in both studies did not find the UI confusing but two participants found EGF confusing to use in study #1. When participants were instructed to wait for the EGF motion to complete before executing the motion in study #2, the confusion in using the EGF was eliminated. The positive comments during the interview sessions with regards to the direct benefits of the system over the log sheet and the advantages of having a guide leg also further contribute to the support of H3.

VI. CONCLUSION AND FUTURE WORK

This paper demonstrates the utility of visual feedback and guidance during the performance of rehabilitation exercises. Two studies were conducted validating the use of visualization and guidance with healthy participants. The results showed that while using EGF, the variability in MAX and MIN joint angles was lower than without using EGF, indicating more consistent exercise performance while using EGF. Participants also showed evidence of performing the exercises more correctly after using EGF, resulting in lower error values. User feedback showed that participants found the UI and EGF helpful in performing the motions, and the UI and EGF did not introduce confusion. Using EGF was preferred by the participants over the alternative method.

Future work includes replicating this study with rehabilitation patients and observing how the qualitative and quantitative results differ from the healthy population. Qualitative results from rehabilitation patients will help improve the system to better accommodate clinical use.

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