Personal Mobile Devices to Assist with Wrist Rehabilitation at Home

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Abstract
We present two modalities using mobile devices to assist patients with home-based wrist rehabilitation exercises. The first modality is a standalone smartwatch application that tracks the wrist’s Range of Motion (ROM) and visualizes real-time exercise data. The second modality uses a smartphone to mirror the visualizations displayed on the smartwatch to overcome screen invisibility while rotated. In this poster, we report on our pilot study and the qualitative results of the two solutions. Results show that in terms of usability, the smartwatch-only modality score surpassed the mirrored-display. However, participants preferred the mirrored-display modality more for home-based usage.

CCS Concepts
• Human-centered computing → Empirical studies in visualization; Ubiquitous and mobile devices;

1. Introduction
Wrist and hand injuries are prevalent in sports [Ret03] and work environments [CLS*22], necessitating rehabilitation and physiotherapy interventions to foster recovery and improve joint function. The conventional wrist rehabilitation exercises conducted under the guidance of physiotherapists are called Range of Motion (ROM) exercises. They consist of a set of rotational movements around the wrist joint. During traditional rehabilitation sessions, physiotherapists use a Goniometer Ruler to measure joint limits and ROM. Patients are asked to perform prescribed exercises at home between regular sessions of rehabilitation. However, many factors keep patients from adhering to home-based exercises [JMMG10, Bas03]. For example, they might lack motivation [MPWR00] or do not feel confident performing the exercise [JMMG10], which can postpone the recovery and lead to serious problems. Biomechanics and human-computer interaction research contributed to practical and automated applications for personal wrist rehabilitation. On the one hand, some of these applications consist of robot-assisted devices with no [GRR*19, SCMB18] or limited visual feedback [HMAMSA*18] (i.e., the device only shows textual instructions or parameter settings). On the other hand, a few solutions recourse to devices with interactive touchscreens (e.g., devices that are available at home like smartphones [MBS*16]), and others employ haptic interfaces (e.g., sensor gloves [HKD*14, DPS16] and haptic interfaces [DPS16]) to engage patients in performing the exercise using a mobile mixed reality game [HKD*14], or in virtual reality [DPS16]. Other solutions employed Inertial Measurement Unit (IMU) sensors to track the movement of the full arm in general and the wrist more specifically. Costa et al. [CRO*20] proved the validity and reliability of two wearable inertial sensors for measuring active ROM of the elbow and wrist. They used external software (i.e., running on the laptop) to visualize in real-time the ROM measurements, and they mirrored movements on a virtual arm model. To facilitate the use of such rehabilitation systems outside of complex lab settings and without requiring expert intervention, our solutions focus on personal and off-the-shelf devices (i.e., a smartwatch and a smartphone) dotted with sensing and display capabilities. Additionally, we explore mobile visualization [LDIC21] for wrist rehabilitation, an area that has seen limited investigation with mobile devices. Building on previous research [BBB*19, BBB*23], we use simple micro visualizations, such as, radial and bar charts, in providing guidance to patients undergoing wrist rehabilitation.

We consider two modalities for assisting home-based wrist rehabilitation to contribute to this line of research. For the first modality, we use a smartwatch as a lightweight device with motion-tracking capabilities (i.e., IMU sensors) to track the three-dimensional rotational movements of the wrist. Then, we provide real-time visual and haptic feedback to assist the patient during the ROM exercises. However, reading visualizations from a moving display can be problematic due to the invisibility of the smartwatch’s screen when the wrist is rotated. We addressed this issue with the second modality by mirroring the visualizations of the smartwatch on a smartphone. In this poster, we report on our qualitative evaluation to assess participants’ preferences when using the two modalities.

2. Visualization Design
The two modalities, running on the smartwatch and the smartphone, show the same visualizations but with a slight difference in their layout. On the right side of the smartwatch screen (Figure 1, left) and in the middle of the smartphone screen (Figure 1, right), we display a radial bar chart depicting the range of the rotation angle the wrist can perform on both sides of each rotation axis (x-, y-,
Participants started performing the ROM exercises following an arrow indicating the direction of the movement. Similar settings were applied to both modalities. The main difference was that participants were asked to read the visualizations solely from the smartphone.

3.2. Apparatus

We implemented a Wear OS smartwatch application deployed on a Fossil Carlyle HR Gen 5. We used a Google Pixel 4a smartphone running Android 10 for the mirrored display application. The data was sent to the smartphone via a UDP connection. Participants were sitting on a chair, and we placed a table in front of them, on which we attached a flexible stand for the smartphone (Figure 1, right). The stand was viewed from a distance $\approx 65$ cm, and its height was adjusted to participant’s preference.

4. Results and Discussion

We used the NASA Task Load Index (NASA TLX) questionnaire (0: low rating – 20: high rating) and the System Usability Scale (SUS) questionnaire (1: strongly disagree – 5: strongly agree) to evaluate participants’ preferences and overall performance with the two modalities. At the end, participants were asked to compare the two modalities by also answering the following questions:

- Q1: Which condition did you prefer the most?
- Q2: Which condition was most enjoyable?
- Q3: Which condition was most helpful?
- Q4: Which condition was most practical?
- Q5: Which condition is more suited for use at home?

In general, the usability rates for both conditions were similar. Overall, participants rated the task load as low. However, they found the task more physically ($M = 5.5$) than mentally ($M = 2$) demanding. In contrast, they found that they were successful in accomplishing the task with both conditions ($M = 18$ and mirrored-display $M = 19.5$). The smartwatch-only modality received an average SUS score of 73.50. This score is classified as GOOD [BKM09]. In contrast, the mirrored-display modality received a slightly lower average SUS score of 68.25 and is classified as OK. Ultimately, the smartwatch-only condition was more enjoyable and practical for participants. However, participants preferred the mirrored-display condition and found it more helpful and suitable for at-home usage. A recurrent comment was that the visualizations were not self-explanatory. This issue is common among micro visualizations since, due to the limited display area, they often lack details about the displayed data e.g., axis labels and titles. For future studies and real-life usage scenarios, a phase of familiarization with the visualizations should be considered. To conclude, the reported feedback indicated that both modalities had their limitations: 1) the screen occlusion and 2) not being able to view the wrist and the visualization simultaneously. For this, a more optimized solution should allow displaying situated visualizations, e.g., in AR, around the smartwatch. Moreover, future work should investigate visualization reading performance between modalities.

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Figure 1: The two modalities. Left: smartwatch only. Right: smartwatch together with smartphone.
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References


