Personal Mobile Devices to Assist with Wrist Rehabilitation at Home

F. Grioui[1], P. Antoniadis[1], X. Yu[1], and T. Blascheck[1]

[1]University of Stuttgart, Germany

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*-,

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

and z-axis). The radial bar chart is split into two halves, with the split referring to an angle of 0°. The radial bar chart has a length corresponding to the absolute maximal angle the wrist can reach.

One repetition during an exercise session consists of a one-sided rotation that can be described as a back-and-forth movement between the initial position and the point the wrist reaches when rotating toward the maximal angle. When the movement starts, a radial progress bar (in red) is displayed on top of one side of the radial bar chart to show the current rotation angle of the wrist. The smartwatch vibrates to indicate that the absolute maximal rotation angle is reached. After each completed repetition, to keep track of the overall performance, we display the wrist rotation angle reached as a bar chart and the average speed with which the back-and-forth movements were performed as two points on top of each bar. Once n movements are performed, with n being the targeted number of repetitions, we end up with two bar charts—one for each side—depicting n bars and two line charts overlain on the bar chart, connecting the points for the speed (one each for the forth and back movement). We show these two combination charts on the left side of the smartwatch screen (Figure 1, left). For the smartphone, the summary bar chart for the left wrist rotation is depicted on the left and on the right sides for the right wrist rotation (Figure 1, right).

3. Study

We conducted a qualitative within-subject study with ten healthy participants, including 8 males, all students aged between 23–30 years ($M = 26$). Only 3 participants had undergone physiotherapy procedures in the past, two for the knee and one for the back, but no one had any experience with wrist rehabilitation. We asked participants to perform the ROM exercises using the two modalities.

3.1. Procedure and Setup

Participants were instructed to perform identical tasks across the two modalities. Each modality required the completion of five iterations (10 repetitions) for each ROM axis, amounting to 30 wrist rotations per modality. While performing the back-and-forth rotation movements, participants could gauge their current progress with the radial chart. Then, check the history of their overall performance with the combination chart. After each modality, participants filled out a questionnaire to rate their performance. For better tracking of the rotation angle, we placed the smartwatch on the back of the hand (Figure 1). After validating the setting parameters (i. e., the rotation axes to perform and the number of repetitions), 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 ≈ 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 (smartwatch-only $M = 2$ and mirrored-display $M = 2.5$) demanding. In contrast, they found that they were successful in accomplishing the task with both conditions (smartwatch-only $M = 18$ 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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References

[Bas03] BASSETT S. F.: The assessment of patient adherence to physiotherapy rehabilitation. *NZ Journal of Physiotherapy 31*, 2 (2003), 60–66. 1

[BBB*19] BLASCHECK T., BESANÇON L., BEZERIANOS A., LEE B., ISENBERG P.: Glanceable visualization: studies of data comparison performance on smartwatches. *IEEE Transactions on Visualization and Computer Graphics 25*, 1 (2019), 630–640. doi:10.1109/TVCG.2018.2865142. 1

[BBB*23] BLASCHECK T., BESANÇON L., BEZERIANOS A., LEE B., ISLAM A., HE T., ISENBERG P.: Studies of part-to-whole glanceable visualizations on smartwatch faces. In *IEEE 16th Pacific Visualization Symposium (PacificVis)* (Washington, DC, USA, 2023), IEEE Computer Society Press, pp. 187–196. doi:10.1109/PacificVis56936.2023.00028. 1

[BKM09] BANGOR A., KORTUM P., MILLER J.: Determining what individual sus scores mean: adding an adjective rating scale. *Journal of usability studies 4*, 3 (may 2009), 114–123. 2

[CLS*22] CHEN N., LI G., SUN X., ZHANG M., ZHANG H., LING R., LIU Y., LI G., REN Z., YIN Y., SHAO H., ZHANG H., LI J., QIU B., WANG D., ZENG Q., LIANG Z., WANG R., CHEN J., ZHANG D., MEI L., LIU Y., LIU J., ZHANG C., LI T., WANG Z., CHEN Q., JIA N.: Prevalence status and associated factors of wrist postural injury in the chinese occupational population. *Frontiers in Public Health 10* (2022). URL: https://www.frontiersin.org/journals/public-health/articles/10.3389/fpubh.2022.1047814, doi:10.3389/fpubh.2022.1047814. 1

[CRO*20] COSTA V., RAMIREZ O., OTERO A., GARCIA D., URIBARRI S., RAYA R.: Validity and reliability of inertial sensors for elbow and wrist range of motion assessment. *PeerJ 8* (08 2020), e9687. doi:10.7717/peerj.9687. 1

[DPS16] D'AURIA D., PERSIA F., SICILIANO B.: Human-computer interaction in healthcare: How to support patients during their wrist rehabilitation. In *2016 IEEE Tenth International Conference on Semantic Computing (ICSC)* (2016), pp. 325–328. doi:10.1109/ICSC.2016.21. 1

[GRR*19] GARCÍA G., RAMÍREZ V., RAMÍREZ O., RUEDA J. L., TORRES C. R.: Simplified design of a device for wrist rehabilitation. In *New Trends in Medical and Service Robotics* (Cham, 2019), Carbone G., Ceccarelli M., Pisla D., (Eds.), Springer International Publishing, pp. 35–42. doi:https://doi.org/10.1007/978-3-030-00329-6_5. 1

[HKD*14] HALIC T., KOCKARA S., DEMIREL D., WILLEY M., EICHELBERGER K.: Momires: Mobile mixed reality system for physical and occupational therapies for hand and wrist ailments. In *2014 IEEE Innovations in Technology Conference* (2014), pp. 1–6. doi:10.1109/InnoTek.2014.6877376. 1

[HMAMSA*18] HISHAM MOHD ADIB M. A., MAT SAHAT I., AHMAD Z., MOHD HASNI N. H., DAUD N., MOHD REDZUAN N. S.: Enhancing the wrist-t device using touchscreen panel for the traumatic brain injury patient. In *2018 IEEE-EMBS Conference on Biomedical Engineering and Sciences (IECBES)* (2018), pp. 437–441. doi:10.1109/IECBES.2018.8626715. 1

[JMMG10] JACK K., MCLEAN S. M., MOFFETT J. K., GARDINER E.: Barriers to treatment adherence in physiotherapy outpatient clinics: A systematic review. *Manual Therapy 15*, 3 (2010), 220–228. doi:https://doi.org/10.1016/j.math.2009.12.004. 1

[LDIC21] LEE B., DACHSELT R., ISENBERG P., CHOE E. K. (Eds.): *Mobile Data Visualization*. Chapman and Hall/CRC, 12 2021. doi:10.1201/9781003090823. 1

[MBS*16] MATERA G., BOONYASIRIKOOL C., SAGGINI R., POZZI A., PEGOLI L.: The new smartphone application for wrist rehabilitation. *The journal of hand surgery Asian-Pacific volume 21 1* (2016), 2–7. doi:10.1142/S2424835516400014. 1

[MPWR00] MACLEAN N., POUND P., WOLFE C., RUDD A.: Qualitative analysis of stroke patients' motivation for rehabilitation. *BMJ 321*, 7268 (2000), 1051–1054. doi:10.1136/bmj.321.7268.1051. 1

[Ret03] RETTIG A. C.: Athletic injuries of the wrist and hand. *The American Journal of Sports Medicine 31*, 6 (2003), 1038–1048. PMID: 14623677. URL: https://doi.org/10.1177/03635465030310060801, doi:10.1177/03635465030310060801. 1

[SCMB18] SERRANO D., COPACI D., MORENO L., BLANCO D.: Sma based wrist exoskeleton for rehabilitation therapy. In *IEEE/RSJ International Conference on Intelligent Robots and Systems* (2018), pp. 2318–2323. doi:10.1109/IROS.2018.8593987. 1