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Conducting individualised hand therapy evaluation with around-device hand movements

Xiangdong Li[1] · Kailin Yin[1] · Siyang Shen[1] · Hanfei Xia[1]

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Abstract
Office workers often resort to therapeutic systems to address muscular and nerve disorders caused by poor gestures and extraordinary workloads. These systems deliver effective treatment with a playable experience. However, the therapeutic evaluation still heavily relies on occupational therapists' diagnose, which is time-consuming and subjective. This highlights the necessity for a system that adheres to standard treatment protocols and enables individualised therapeutic evaluations. In this study, we proposed a hand therapy system based on around-device hand movements with a capacitive-sensing mobile phone case to realise instant yet approximate hand therapy evaluation. Moreover, we conducted empirical studies to investigate the usability and acceptability of this system and its potential influence on office workers' willingness to take hand therapy exercises during working hours. The results showed that this instant yet approximate evaluation system can significantly improve the workers' hand therapy frequencies during working intervals. Furthermore, it can quantitatively measure and report on individual therapy performances, helping office workers understand their therapy outcomes and promoting their willingness to take therapeutic hand exercises. Our results introduce a new perspective for designing mobile systems for well-being.

Keywords Hand therapy evaluation · Hand movement · Around-device interaction · Mobile phone device

1 Introduction

Office workers are often in intense working environments and adopted unhealthy hand gestures for extended periods. This behaviour predisposes them to muscular and nerve disorders, adversely affecting both corporate productivity and personal well-being. For example, over 5 percent of US adults suffer from hand-related issues and require therapeutic intervention during working hours [6]. Systems and applications have been developed to support playful and portable therapeutic activities to address the problem, while few are

✉ Kailin Yin
klyin@zju.edu.cn

1 College of Computer Science and Technology, Zhejiang University, 38 Zheda Road, Hangzhou, People's Republic of China

dedicated to individualised hand therapy evaluation in office environments [14, 41]. The evaluation still heavily depends on unique diagnose by occupational therapists, typically lasting from 20 min to several hours in hospitals and rehabilitation centres [16]. The evaluation process is time-consuming and subjective, as it usually follows a set of standard treatment protocols with therapists' expertise and skills.

Although some countries have work-related regulations permitting office workers to take time for such treatments, these are impractical for the majority of office workers who need short, work-hour compatible therapeutic hand exercises. Workers also require efficient therapy evaluations that provide immediate individual feedback based on their personal hand exercises, to help them understand their therapy outcomes and adjust their exercise plans [29]. Additionally, many office workers, including game developers and intensive programmers, have insufficient knowledge about effective hand therapies and need a new device with integral measurement scales for post-exercise hand therapy evaluation.

Mobile devices with capacitive sensing have become ubiquitous in interactive products, spurring various research attempts to incorporate them into physical therapy [15]. Nevertheless, previous works of capacitive sensing and other in-air interactions have primarily focused on user interactions, rarely considering their potential for therapeutic activity evaluation. While some studies have investigated therapy gamification via in-air gestural interactions, most still focus on system usability and user experience rather than therapy evaluation. Existing research has adopted capacitive sensing technology to generally reflect overall ratings, yet a significant gap remains between therapy evaluation and critical therapeutic applications. Given the growing importance of physical therapy for office workers and the rapidly increasing number of people requiring hand therapy, it is essential to consider an individualised hand therapy evaluation system which could be automatically conducted with mobile therapeutic tools.

In this study, we proposed a hand therapy system designed for individualised therapy evaluation. This system was based on around-device hand movements acquired by a capacitive-sensing mobile phone case and facilitated the interactive and immediate evaluation of hand therapy sessions. We developed a game application to accompany this device, which uses capacitive sensing to detect hand movements around the mobile phone and offers users a gamified hand therapy experience, complete with immediate evaluation outcomes. To assess the usability and acceptability of this instant yet approximate evaluation approach in real-world work scenarios, we conducted a usability test and an empirical study. The results showed that this system enabled office workers to effectively evaluate their hand therapy outcomes and adapted their therapeutic strategies as needed, promoting their willingness to take therapeutic hand exercises. Furthermore, we explored potential future applications of this research in the field of healthcare and human–computer interaction.

The main contributions of this study are two-fold:

(a) We developed a hand therapeutic tool by modifying a capacitive sensing mobile phone case and developing a game application, realising around-device hand movements measurement and instant yet approximate evaluation. It filled the gap in existing studies that focus on gesture interactions but lack individualised hand therapy evaluation for office workers. The study enriched the domains of gamified hand therapy exercises and evaluation.

(b) We conducted a series of empirical studies to demonstrate the effect of the mobile evaluation system of individualised hand therapy in motivating the willingness of office workers to take hand therapeutic exercises during work breaks. In addition, automated assessment in domains where less prior knowledge available represent a novel application of mobile interaction.

2 Related works

2.1 Hand therapy

Upper extremity syndromes such as numb and painful hands/wrists negatively impact an individual's ability to participate in activities [40], and the number of office workers with upper extremity syndromes is increasing [6]. Hand therapy (HT) [9], a practice in which individuals exercise their hands and wrists at regular intervals to reduce pressure on the muscles and nerves of their hands, is used to treat these syndromes. It is beneficial to assist with reducing hand pain and preventing further damage to the hand [19, 44].

Hand therapy consists of hand exercises and therapy evaluation. Hand exercises involve a set of muscular movements and stretches performed over a required period, e.g., bending and straightening the wrists. The exercises can be performed by individual users with or without therapeutic devices. In contrast, therapy evaluation is a uniquely skilled process that relies heavily on therapists' subjective experience [42]. Such evaluations have traditionally been conducted in hospitals and rehabilitation centres, where the therapist could check users' personal information (e.g., medical history) and test their hand functions against evaluation protocols.

2.2 Mobile device for therapeutic use

Researchers have used mobile phones to develop various interactive systems specifically targeted toward human health and well-being [15]. For example, mobile phones have been adopted for smoking cessation consultancy [33], diabetes management [13], cardiac rehabilitation [3] and to provide posture risk reminders [25]. Especially for office workers, mobile applications have been developed to reduce sedentary behaviour [10] or to promote mobility during work breaks [5].

In the field of hand therapy, advances in processing power have enabled mobile phones to serve as appropriate hand therapy intervention tools for individualised hand exercises and evaluations [43]. For example, smartphone applications, such as Fruit Samurai and Catch the Fish, have been used as an intervention strategy to encourage a range of motion and proprioceptive training for hand therapy clients with trapeziometacarpal arthrosis or distal radius fractures [1]. DrGoniometer is an innovative application that calibrates measurements of joint angles from photographs taken via a smartphone camera, providing both accurate measurements and immediate retrieval of patient data information [37]. Goniometer Pro is a new smartphone application designed to measure clients' active wrist range of motion (ROM), proving useful in wrist physical examination [35]. Dexteria is another application that encourages finger dexterity and isolation of movements, developed specifically for training fine motor coordination in the non-dominant hand [39]. In addition, wearable-based systems have been developed for hand therapy interventions cooperated with mobile phones, such as GymSkill, a balance board with a top-mounted smartphone that analyses users' physical activity during balance training [20], GonioSense, a physical therapy device with integrated goniometers that measures limb movement during exercises [36], and Funtherapy, a wearable device that allows physical therapy monitoring with a built-in game and physical therapy exercises [41]. Additionally, applications of augmented reality and virtual reality have been adopted for hand rehabilitation [7, 34].

Interactive technologies such as capacitive sensing have increasingly been integrated with mobile phones and enabled around-device interaction. In capacitive sensing, the capacitance between two electrodes positioned a specific distance apart changes when the external shapes influence the existing electric field. Therefore, active capacitive sensing can detect physical properties such as touch and proximity [15] by measuring changes in the capacitive coupling between a human body/hand and conductive electrodes. Mobile phones can sense multitouch events and in-air hand movements in the device's peripheral space equipped with capacitive electrodes of customised shapes. For example, a mobile phone whose surfaces are coated with arrays of copper foil capacitive-sensing electrodes can support full-touch sensing interactions [24]. Studies have also applied capacitive sensing to the back of mobile phones to record users' device grip gesture styles [23] and large-scale textile pressure sensor arrays have been developed [8]. Moreover, with swept-frequency capacitive sensing, mobile phones can estimate complex human hand configurations [38]. In the domain of health and rehabilitation, mobile device-based capacitive sensing is embedded in typical everyday objects to achieve unobtrusive health informatics sensing for the elderly [46]. This technology can also serve as a flexible capacitive surface sensor for long-term and large-scale health monitoring [21, 22]. Together with other sensors, mobile phones are becoming portable and versatile measurement tools for healthcare intervention [11], such as investigating the influence of walking speed on mobile phone use with capacitive sensing [30].

2.3 Hand therapy evaluation

Quantitatively measuring users' hand movements has become an important focus in the hand therapy field because individualised feedback could increase users' long-term motivation [20] and foster the correct use of hand exercises. To date, hand therapists evaluate hand exercise mainly through visual and verbal inspections, e.g., asking questions and reviewing videos, which is a subjective approach to quantifying therapeutic outcomes [42]. Self-monitoring and self-assessment [2] based on wearable body sensors has become popular solution in the healthcare domain, but these devices are predicated upon users wearing dedicated systems or sensors, and few of these devices are optimised for office use.

Scales of hand therapy evaluation are essential for conducting individualised therapeutic evaluation and there are many approaches for assessing human body nerve and motion functions. For example, several clinical studies have compared different hand therapy evaluation procedures and evaluation metrics and revealed common procedural approaches for hand therapy evaluation including checking clinical history information and physical examinations [12, 28]. Clinical history information is usually checked by therapist assistants to acquire and assess any necessary clinical history information, and physical examinations are conducted with a set of tests and measures based on different therapeutic conditions, and their administration requires unique expertise and experience. The physical examination involves hundreds of evaluation scales and sub-scales regarding the different hand nerves and muscles and some of the scales, e.g., aerobic endurance, are unsuitable for office use. In this work, we selected four key scales for hand therapy evaluation: hand joint mobility, motor function, muscle performance, and sensory processing [18, 45], which are compatible with individualised hand therapy evaluation in office environments. These evaluation scales are also used for simplified carpal tunnel syndrome diagnosis [9] and have been proven effective.

2.4 Lessons learned

The preceding review shows that large numbers of mobile systems and applications have been developed for human healthcare and well-being, and gamification and wearable sensors have been employed to assess physical performance as shown in Table 1. Despite the popularity of different applications and wearable systems for hand therapy is growing, prior research highlights the movement promotion of hand and wrist, and how to support evaluation of individualised hand therapy without other wearable devices in office environments is ambiguous.

We were motivated to design a mobile system capable of quantifying the effects of individual therapeutic activities immediately after exercise and to advance the understanding of how to stimulate office workers to conduct hand therapy during office breaks. The expected benefits of the therapeutic evaluation system included increased convenience for busy office workers, offering flexibility and easier management compared to the traditional need for physical visits to a therapist. Through the instant yet approximate evaluation, we aimed to move the control and management closer to the user and the context of the work-related issue.

3 Methods

We developed a hand therapy system by modifying a mainstream Android smartphone case and designing a matching mobile game to perform individualised hand therapy evaluation in office environments. The game guided users to perform specific hand movements and the modified case detected hand movements and evaluated the performance. The mobile phone case was chosen as the target prototype due to its ability to seamlessly integrate capacitive sensing with mobile phones and their ubiquity in office environments, enabling workers to use the hand therapy system conveniently during office breaks.

3.1 Hardware design

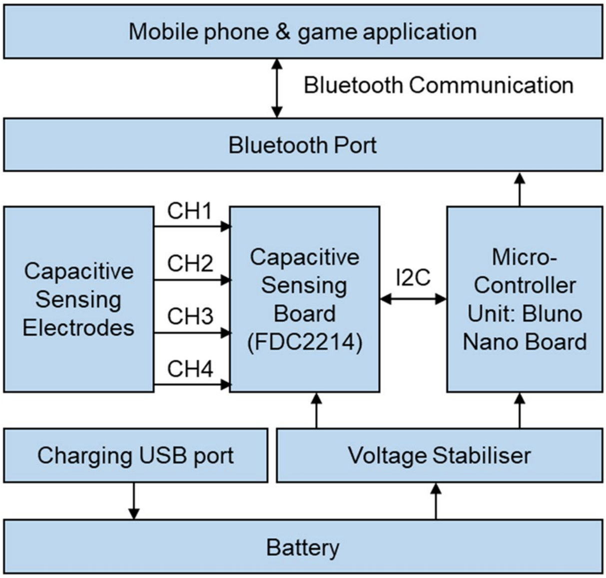
An Android smartphone case was modified to detect hand movements. The case was mainly made of silica rubber and mounted on the back of the original mobile phone, and it was equipped with four components: capacitive sensing electrodes, a multi-channel sensing data processing board, a microcontroller board with Bluetooth communication capability, and a battery. The capacitive sensing electrodes, made of copper foil tapes, were affixed on the curved surfaces at the four sides of the mobile phone case, and the other three components were mounted on the inner side of the mobile phone case. The connections of these four components were detailed as follows (Fig. 1) and they could be assembled with a detachable rear cap of the mobile phone case (Fig. 2a).

The capacitive sensing electrodes copper foil tapes were 0.1-mm thick, and cut to 8×52 mm to fit the short sides of the case and 8×95 mm to fit the long sides (Fig. 2b). They were wired to corresponding capacitive sensing channels on a flexible circuit board, which was based on the Texas Instruments FDC2214 capacitance sensing chip (Fig. 2c). This chip supported four capacitance sensing channels, connected to corresponding electrodes and an I2C interface, connected to a Bluno Nano board (Fig. 2d). This board used an ATMEGA328P chip as the core processor and served as the microcontroller unit (MCU). The MCU read raw data from the capacitive sensing board in

Table 1 Summary of current hand therapy applications

Name	Category	Therapeutic use
Fruit Samurai [1]	Mobile application	An application that encourages the appropriateness of a prescribed range of motion exercises, including active palmar abduction of the thumb and finger proprioception, for individuals with trapeziometacarpal arthrosis
Catch the Fish [1]	Mobile application	An application that assists with increasing range of motion and grip strength and decreasing pain for individuals with hand osteoarthritis
DrGoniometer [37]	Mobile application	An application that measures clients' active wrist range of motion
Goniometer Pro [35]	Mobile application	An application that provides accurate measurements and immediate retrieval of patients' joint angles via the smartphone camera
Dexteria [39]	Mobile application	An application that encourages finger dexterity and isolation of movements, developed specifically for training fine motor coordination in the non-dominant hand
GymSkill [20]	Mobile application with wearable devices	A smartphone system with a balance board for physical activity during balance training
GonioSense [36]	Mobile application with wearable devices	A wearable-based range of motion sensing and measurement system for body joints
Funtherapy [41]	Mobile application with wearable devices	A wearable device that allows physical therapy monitoring with a built-in game whose dynamics force the user to perform physical therapy exercises
Microsoft Kinect [7]	VR application	A VR game-based rehabilitation tool using sensing devices to capture and quantitatively assess the movements of patients under treatment

Fig. 1 Connections of four components



28-bit hexadecimal format, representing the ratio of the detected to reference capacitance value, and making capacitive sensing environmentally adaptive. To collect the electromagnetic noise-free capacitive sensing measurements in a more readable format, the least significant digits of the data were removed and the raw data was transformed into a 12-bit decimal integer. The maximum processing frequency was limited to 100 Hz to preserve battery life and limit MCU heat, sufficient for real-time hand motion detection.

The processed integer data were subsequently sent to the Bluetooth port on the Bluno Nano board, which included an embedded antenna. The Bluetooth module handled connection requests from mobile phones and the port stored only the latest readings and overwrote outdated data. A 3.7 V 750-mAh Li-Neon battery powered the capacitive-sensing and MCU

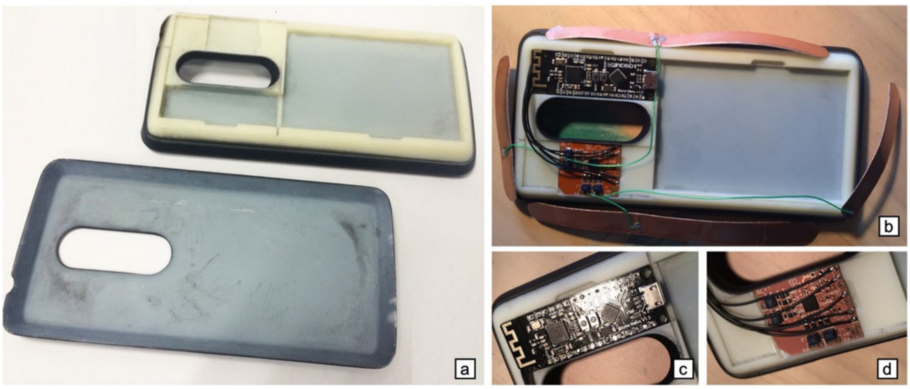


Fig. 2 The mobile phone case: (**a**) the front face and the rear face; (**b**) the capacitive sensing electrodes on the mobile phone case; (**c**) the flexible capacitive sensing board; (**d**) the Bluno Nano board served as micro-controller unit (MCU)

boards, supporting over 40 h of continuous capacitive sensing. Electromagnetic noise from voltage fluctuations was minimized using a voltage stabilizer and a USB charging interface.

Furthermore, we put the mobile phone case in multiple open-space locations (e.g., on desktops, on the ground, on outdoor desks, carpets and office chairs) to simulate work in various office situations, and tested the working ranges of the capacitive-sensing electrodes and the consistency of their readings. We found that the long capacitive sensing electrodes detected up to an average maximum of 210 mm, with an accurate detection range of 0 (touch event) to 150 mm, and the short electrodes detected up to an average maximum of 100 mm, with an accurate detection range of 0 to 50 mm. The capacitive sensing electrodes provided submillimetre accuracy within their accurate detection ranges, allowing effective hand movements detection as minute as 0.1 mm.

3.2 Mobile game application design

Game applications have been proven to benefit hand therapy as an engaging alternative to traditional therapy options for office workers [17] and have a positive influence on treatment adherence [27]. Therefore, we designed an Android game named Boat Adventures to provide playable interaction with the mobile phone case while measuring users' hand movements (Fig. 3).

The game used a boat as an intuitive metaphor for dynamically moving objects and the mission for users was to use hand movements to control the boat to minimise collision with any static or moving barriers. There were three difficulty levels of the game based on the allowed number of collisions, and the game ended when the collision limit was exceeded. The boat was subjected to gravity, vortex attraction forces and external forces incurred by users' hand movements, therefore careful and timely manipulation was needed. The game application was developed based on the AndEngine, a free Android 2D OpenGL game engine that could simulate physics-based effects.

There are multiple hand gestures (e.g., push, paddle and tap) for users to control the boat (Fig. 4). For example, when the user's hand approaches the right side of the mobile phone case, the boat is pushed toward the left of the screen and vice versa; when the hand moves from bottom to top, the boat accelerates forward faster. The pushing force is co-determined

Fig. 3 Screenshots of the game application

by hand movement velocity, direction and frequencies. Inertia forces are also applied based on the boat's speed.

Upon completion or failure of this game, the game application presented the evaluation results for the four evaluation categories, including joint mobility, motor function, muscle performance, and sensory processing, to reveal the details of the users' hand therapy performance. Moreover, the application stores the latest 10 evaluations, enabling users to monitor the progress or decline of their specific hand functions over time.

Joint mobility refers to a person's ability to move hand joints and can be measured by the types of hand gestures used during game interaction. The interaction involves four hand postures, each associated with a unique hand joint gesture.

Muscle performance refers to the capability of hand-associated muscles to exert force. We employed speed as a muscle performance indicator, as it typically reflects the muscle power produced per unit of time. The measurement of hand movement velocity was calculated as follows:

$$V = \frac{\sum_{k=1}^{12} (R_k - R_{k-1})}{12t} \tag{1}$$

where V is the hand movement velocity, R is the original reading, 12 is the count of offset readings used for random noise smoothing, and t is the elapsed time since the last reading. The equation also implies hand motion directions: a negative V indicates a decrease in capacitance, which occurs when the hands move closer.

Motor function refers to the ability to learn or demonstrate the skilful and efficient maintenance and control of voluntary postures and movement patterns and can be measured by the frequencies of hand movements in the game interaction. Hand motion frequency was calculated as follows:

$$F = \frac{N}{T} \tag{2}$$

where F is the hand motion frequency, N is the number of directional changes and T is the duration.

Sensory processing refers to the ability to acquire information derived from the environment and the body, e.g., physiological responses, and is used to assess movement. It could be measured effectively by users' response times. The response times are calculated by:

$$Rt = \frac{1}{F} \tag{3}$$

where Rt is the response time and F is the hand motion frequency.

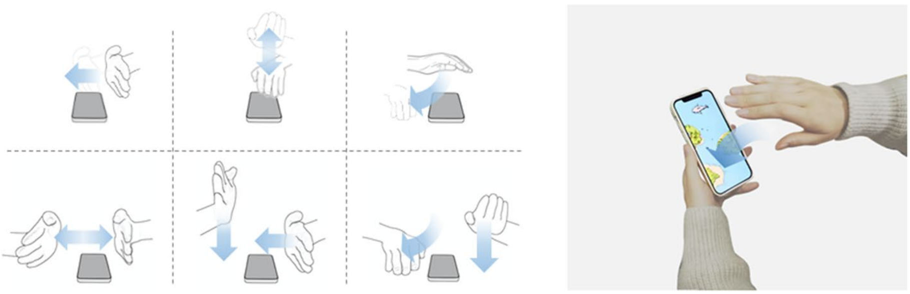


Fig. 4 Examples of hand gestures and movements in interaction with the hand therapy device

4 Usability test

We conducted an experiment to assess the usability of the hand therapy system and the acceptability of the individualised hand therapy evaluation during work breaks. Usability evaluation scales were derived from the system usability scales (SUS) [4]. The employment of SUS was appropriate due to the following reasons: (a) it is a quick method well-suited for office working environments; (b) the ten template questions can be modified and extended to accommodate diverse situations and meet individual requirements; (c) SUS benchmarks across various application domains facilitates straightforward comparisons between the usability of the proposed hand therapy device and existing industrial standards; and (d) it can be simultaneously used with other metrics, e.g., device acceptability, as a comprehensive measurement. Besides, acceptability evaluation scales were based on Nielsen's definition of practical acceptability: costs, compatibility, and device reliability [31].

4.1 Usability test settings

We recruited 41 workers (13 female and 28 male), from different departments of an industry-leading mobile phone game development company, with an average age of 25.4 (SD = 3.52). All the workers volunteered to participate in the study and reported no eyesight or hand diseases.

The survey was carried out in workers' office cubicles in random orders during afternoon breaks. The experiment was conducted with a mobile phone, attached to the modified case, and equipped with the Boat Adventures game application. After a two-minute introduction to the system's functionality and usage, the participants engaged in hand therapy trials without time limitation. The average duration of these trials was 8.05 min (SD = 2.21). After the trials, participants were required to complete a 5-item Likert-scale questionnaire (Appendix A) and received informal interviews hosted by the experimenter. The interview aimed to collect qualitative feedback from the workers regarding their experience with the system, e.g., satisfaction with the device setup and aesthetic appeal of the game's appearance.

4.2 Usability test results

The results showed that the average working time for the participants was 10.22 h per day (SD = 3.53). All of them suffered from varying levels of hand fatigue, numbness and pain after such long working hours (M = 2.88, SD = 1.07). In the interviews, the participants suggested a perceived correlation between their working gestures, work durations, and their hand-related issues. Specifically, they mentioned their discomfort such as hand and/or wrist strain, aching shoulders and neck, dry eyes, and back pain.

Before the trials, the participants showed a low willingness to conduct hand therapy in the office (M = 2.49, SD = 1.88) and weak motivation for taking immediate therapeutic action (M = 1.98, SD = 0.46). They commented that their hand therapy activities were limited, largely due to a restricted understanding of the benefits associated with therapeutic exercise and evaluation outcomes (M = 3.93, SD = 0.33). Other reasons included the limited office space, lack of physical therapy devices, privacy in the public place, interference with ongoing work, and the monotony of exercise.

The participants indicated a good understanding of the hand therapy systems and hand movement evaluation (M = 3.07, SD = 1.56) and a positive attitude towards the system in future (M = 2.80, SD = 0.98). They had highly confident about using the device without additional training (M = 3.59, SD = 1.01). Nevertheless, the participants identified several potential obstacles that could impede the future system utilisation for hand exercise and therapy evaluation, including eye fatigue from prolonged screen viewing, the limited number of games, and the compatibility of the mobile phone case with new phone models.

The participants believed that functions of the hand therapy system were both useful and understandable (M = 3.12, SD = 1.19) and the functional design would influence their attitudes toward future use of this system. The participants expressed a stronger willingness to undergo hand therapy after trials (M = 2.63, SD = 1.37). They commented in interviews that they would have a higher willingness if the system improved its ease of use. Participants showed positive attitudes towards the game application design with aesthetics and functions (M = 3.88, SD = 0.74). Additionally, the workers provided ideas concerning future device designs and hand therapy evaluations, e.g., enabling whole-body exercise, devices integrated with chairs, and exercises that involved social activities.

Concerning the acceptability of the device, the participants showed consistent concerns about device costs (M = 3.90, M = 0.65). 92.7% of them explicitly asked about the cost of the device in interviews, and all of them were satisfied with the overall hardware cost within 100 USD (excluding the mobile phone) and the free game application provided. The results of compatibility of the hand therapy system showed that the participants preferred a device that could universally fit on all existing mobile phones (M = 3.73, SD = 1.20). They also showed explicit preferences for reliable and durable hand therapy systems (M = 3.85, SD = 1.57).

5 Empirical study

The empirical study aimed to investigate the impact of the hand therapy system and individualised hand therapy evaluation on users' willingness to engage in hand therapy within office environments. To measure willingness, we adopted O'Brien's metrics of perceived usability (PUs), aesthetic (AE), novelty (NO), felt involvement (FI), focused attention (FA) and endurability (EN) [32], which had been successfully used to measure the degree of users' task compliance and engagement. A comprehensive analysis of the users' performances was conducted by integrating in-field observations, video analysis and responses from questionnaires.

5.1 Experiment settings

We recruited another 49 workers (14 female and 35 male) from the product design departments of industry-leading information, communication, and technology (ICT) companies, with an average age of 27.9 (SD = 4.55) and an average working hour of 8.58 h (SD = 3.66) per day. They volunteered to participate in the study and none of them had used the hand therapy system before. Before the experiment, the participants self-reported their most frequently used devices (e.g., mouse and keyboard), and their hand-related syndromes. 85.7% of them reported varying degrees of work-related discomfort such as neck pain, backache and hand/wrist fatigue. None of them had previously received any hand therapy nor conducted dedicated in-office hand/wrist exercises.

Participants were randomly assigned to the hand therapy system for full-day trials and had the freedom to use the system without any restrictions on frequency or duration. A webcam was positioned atop the desk monitor to record their desktop activities, including their use of the hand therapy system. Each participant was shown a two-minute introductory video detailing the system's functions and interactions, followed by a five-minute practical use to ensure they were familiar with the configuration and operation. No additional assistance was supplied for the rest of the day. At the end of the day, the participants were required to complete a questionnaire (Appendix B).

5.2 Experiment results

During the three-month period of this study, 49 individual video streams and questionnaires were collected and 171 videos of system usage scenarios were extracted with manual text annotations, indicating an average single-use duration of 8.51 min (SD = 5.22).

The time that participants used the system throughout the 24 h of a day was analysed (Fig. 5). There are two main time spans that device use is frequent (1:00 pm and 6:00 pm), indicating that they were more likely to use the device at specific times of the day (lunch breaks and off-work hours). The frequency of device usage before 8:00 pm was relatively high, indicating that the participants were inclined to use the device during their work hours.

Perceived usability is an important indicator for predicting users' lasting impressions of the experience as worthwhile [32], reflecting their affective and cognitive responses to the system. The questionnaire results and the video analyses were combined to acquire the participants' impressions and practical perceptions of the hand therapy system. The video analysis showed that all the participants used the system smoothly without encountering any major technical barriers. Comments in the questionnaire sheet quoted that "after the Bluetooth connection was set up, using the device was simple". The questionnaire results, which confirmed this finding, showed that there were no significant differences in the device setup difficulty between the device (M = 3.88, SD = 0.50) and a mundane example of Bluetooth headphones (M = 3.94, SD = 0.80, non-parametric Mann–Whitney test, p = 0.44). Similar results were found in the preceding usability test. The overall exercise experience of the system was reported as fun and satisfactory.

Perceptions of visual appearance are another important indicator for system evaluation. The comments in the questionnaire stated that "the case looks normal and is not distracting". Concerning game design, since the capacitive sensing is not hard-coded to specific hand gestures or movements, the participants' responses indicated that "the game animations look vivid", "the game scenes and game information are intuitive", and "the game characters are well designed".

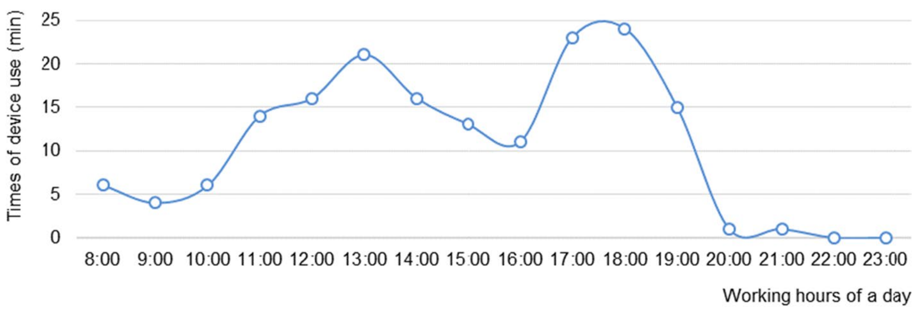


Fig. 5 Results of device use throughout the workday

Novelty is related to the users' interest in the system and their curiosity evoked by the interactions. The questionnaire comments reflected consistent feedback from the participants that they had a great interest in the system's evaluations, including system design, system interactions and evaluation results. They showed the most curious about the around-device hand movements and the therapeutic evaluations. Questions such as "What is the highest score I could get in the game", were frequently asked by the participants.

The sense of involvement reflects users' feelings of being drawn in and having fun. In the video analysis, the majority of device use occurred during working hours, indicating that the participants were relatively more attracted to hand exercise than they had been before. In questionnaire comments, they indicated that they "were first attracted by the hand motion interactions" and "had fun when playing the games with hand motions". The participants described the fun related to devising use as a relaxing experience that tempered work by introducing an entertaining activity. In addition, 75.5% of them commented that the therapy evaluation reports helped to understand the therapeutic outcomes. The video analysis indicated that each participant used the device at least twice during the day and the game not only provided a playful experience but also an immediate understanding of hand therapy evaluation outcomes. As the participants partially commented, they "took the game as a challenge".

Focused attention reveals users' mental concentration associated with the exercises during system use. The video analysis showed no interruptions during the system used for all participants, although the duration varied. In the questionnaire comments, several participants mentioned that the game was "both physically and mentally demanding", and that the game required "careful manipulations" of hand motions during gameplay.

Endurability reflects users' overall feedback on the exercise experience, the perceived success of the physical therapy and the likelihood that they would recommend the system to others. As the video analysis showed, all the participants completed multiple device-use sessions. The questionnaire feedback, together with the results of the preceding usability test, reported no major difficulties in device use. All the participants reported being willing to recommend the device to others ($M=3.74$, $SD=0.82$). They also reported smooth overall experiences when using the system, and that the system efficiently reflected their therapy performances ($M=3.65$, $SD=0.95$). In addition, several participants commented that the use of the system did not involve awkward or privacy issues since the system enable hand therapy in their work cubicles.

5.3 Summary of findings

This empirical study investigated how the mobile hand therapy system influenced users' willingness to perform hand exercises in their offices. The results showed that the device was acceptable to a variety of workers who were easily able to understand both the device functions and hand therapy evaluation reports. Importantly, their willingness and motivation to engage in hand exercises in the office were noticeably enhanced. The participants were particularly interested in and satisfied with the hand therapy evaluation, which was implemented in the form of a hand movement game. We summarise the results in Table 2.

6 Discussion

The study introduced a hand therapy system utilising around-device hand movements acquired by a capacitive-sensing mobile phone case. This system was designed to facilitate instant yet approximate evaluation for individualised hand therapy in office environments.

Table 2 The empirical study results of user engagement

Scales	Measures	Results
Perceived Usability	-Effectiveness of functions -Ease of use -Device use satisfaction level	-Device functions were acceptable and efficient in supporting exercise -No major difficulties in device use -Successful interactions but with varying satisfaction levels
Aesthetics	-Perception of visual appearance -Level of aesthetic appeal	-Device was not distractive -Similar to normal mobile phone cases
Novelty	-Level of interest in the device -Level of curiosity evoked	-Interested in hand motion interaction -Game application and individual evaluation evoked the most curiosity
Felt Involvement	-Level of the feeling of being drawn in -Level of sense of having fun	-Strong sense of being drawn in during gameplay -Had lots of fun during the interactions
Focused Attention	-Level of concentration of activity -Level of smoothness of flows	-Careful manipulations of hand motions were required -Required both strength and skill
Endurability	-Level of success of interaction perceived -Likelihood of recommendation to others	-High level of successful device use -Overall high, but with varying levels of satisfaction

We investigated the usability and acceptability of the system and reported its influence on users' willingness to perform hand exercises during work breaks. The results indicated that the hand therapy system garnered high user engagement, consistent with FunTheory [26]. The study enriched the fields of gamification therapy and in-air hand movement interactions. We developed a capacitive sensing mobile phone case and a game application to encourage workers to engage in hand exercises during work breaks. Notably, this system provided individualised hand therapy evaluation immediately through the therapeutic device, despite the approximated evaluation results. The evaluation offered detailed feedback on the office workers' hand exercises along four key metrics, helping them to better understand their performances during therapeutic hand exercises and enhancing their willingness to engage more in hand therapy.

The finding of this study encompassed both qualitative and quantitative analysis. While quantitative data were included, the ability to make statistically significant claims was restricted due to the relatively limited sample size and the lack of pre-trial clinical assessment. Given the current results, we could not assert that the system would offer significant health benefits to office workers based on proven clinical evidence. However, based on the qualitative evidence gained from meticulous investigations, we remained confident in the system's ability to motivate users to engage in hand therapy exercises and hand performance evaluations. It could eventually contribute to long-term changes in healthcare behaviour in office environments.

The proposed system was proven to be advantageous in motivating workers to exercise their hands and wrists during long work hours, despite the absence of clinical test results. As advised by previous therapeutic studies, frequent hand and wrist gesture adjustments during working is beneficial, provided the working conditions permit [26]. This advice underscores why our study emphasises the usability and acceptability of the system. By understanding the device's influence on user engagement and willingness to engage in long-term hand exercises, we could conclude that this system had positive effects on users' willingness to engage in hand and/or wrist exercises in the specific setting of an office. The improvements in workers' willingness to engage in hand therapy shown in empirical study results could be justified for two reasons. Firstly, the design enhanced the mobile phone's interactive capabilities through the around-device hand movement detection, converting the mobile phone case together with the mobile phone application into an effective tool for hand exercise and instant therapy evaluation. Secondly, the hand therapy evaluation system considered the workers' hand movement trajectories to gauge their overall therapeutic outcomes, providing reasonable accuracy without therapists.

Although this study primarily focused on hand-related clinical knowledge and evaluation scales, it was not meant to replace the role of occupational therapists in hand therapy evaluations. Occupational therapy is typically a specialized field requiring professional licensure for conducting rigorous clinical tests and diagnoses. The study took advantage of the expertise of therapists and their related hand therapy evaluation approaches, integrating four evaluation scales into the interactive mobile phone case. This integration facilitated playable and efficient individualised hand therapy evaluation in office environments without a therapist.

There are possibilities for future development since the availability of the system in various settings has not yet been fully determined. Currently, the system is not sufficiently advanced to be used as a critical therapeutic system in clinical scenarios. However, the study has provided a new understanding of how to design an interactive mobile device that induces workers to engage in active exercises without interfering with their existing office work. Given the demonstrated levels of usability and acceptability, we anticipate that the instant yet approximate evaluation method could relieve the existing shortage of therapists and caregivers by assisting office workers. The evaluation method has demonstrated the potential to address this problem, as noted by the results of this study. In a broader context, the device may be capable of changing workers' everyday working behaviours because they become more likely to exercise during work breaks. In this regard, the device has potential commercial value for the office well-being market. To further improve the device use, our future work will include the socialisation of gameplay and finer hand movement interactions. It is also considered to move the tests to a more non-ICT company in which people are not very used to playing games, which would possibly reveal complementary effects on the results. Moreover, the issues in engaging people in therapeutic activities in the office remind us to consider how dependent are the therapy device on a specific game and how the game can adaptively change the threshold to do the exercise.

7 Conclusion

The study introduced a hand therapy system based on around-device hand movements, captured by a capacitive-sensing mobile phone case. This combination enables instant yet approximate evaluation of individualised hand therapy. To validate the system's usability and acceptability in realistic working scenarios, and importantly, to investigate its influence on office workers' willingness to engage in hand exercises, we conducted a usability test and an empirical study, supplemented by in-field observations and video analysis. The results showed that the hand therapy system stimulated frequent hand exercise during working hours and improved workers' willingness to perform hand exercises due to the feedback from immediate therapy evaluation. We delved into the implications of using such a system for affecting healthcare behaviours and discussed its potential applications in other domains.

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Data availability The datasets generated during and/or analysed during the current study are not publicly available because the current datasets contain privacy information such as participant facial images that are not fully anonymised but are available from the corresponding author on reasonable request.

Declarations

Conflict of interests The authors declare there is no conflict of interest in the submission of this manuscript.

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