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# User Needs for a Robotic Hand Rehabilitation Device in Home-based Therapy Following a Stroke: A User-centered Approach

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The current home-based hand rehabilitation device has issues with functionality and usability, causing patients to discontinue its use and, consequently, waste resources. In this study, we aimed at exploring users' needs and requirements for home-based hand rehabilitation devices, as well as identifying deficiencies in their development and design. We employed a qualitative research method, utilizing semistructured interviews and task observations, to investigate the perspectives and perceptions of individuals regarding user needs for hand rehabilitation devices at home. Our sample comprised 12 hemiplegic patients, 6 caregivers, and 10 occupational therapists. We conducted a contextual data coding analysis using the software NVivo 12.0, where we identified six categories of codes that represent user needs for robotic hand rehabilitation devices in home therapy: fundamental needs, ergonomic needs, emotional needs, accomplishment needs, policy support needs, and safety needs. These codes were subsequently translated into specific requirements. User feedback was used to prioritize the importance of limit protection control as the primary requirement, and emphasis was placed on the role of gamification in motivating individuals to actively participate in the rehabilitation process. The results of this study revealed user needs and requirements that can aid the development of design ideas for home-based hand rehabilitation devices.

## 1. Introduction

Home-based rehabilitation (HBR) can help enhance the quality of life and emotional support from family for hemiparetic post-stroke patients. However, more than 65% of post-stroke patients in Taiwan undergo rehabilitation through outpatient clinics, with the rate of HBR only being approximately 21%.(1) Such outpatient rehabilitation programs involve significant medical resource requirements, time costs, and other expenses.(2) In particular, the COVID-19 pandemic and its sequelae have led to a scarcity of medical resources and increased risk of infection for stroke patients visiting hospitals for outpatient rehabilitation. In contrast to outpatient

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rehabilitation, HBR not only improves functional parameters and physical fitness, but residing in a familiar environment with family also positively affects the emotional state.[3,4]

Hand robot-assisted therapy for post-stroke home rehabilitation has been gaining traction and has greatly developed in recent years. The robotic hand rehabilitation device uses mechanical and electronic components to train and restore hand function. Furthermore, robotic therapy for post-stroke rehabilitation provides high intensity, high repetition, and task specificity, while decreasing medical cost and the workload of physiotherapists.[5–7] However, the current robotic hand rehabilitation device has functional and usability issues, such as being unable to help patients perform daily activities, not fitting the patient's hand size, a complex setup procedure, and being heavy and space-consuming.[8–10] These issues may cause the patient to give up on its use, which hinders rehabilitation, and wastes resources.

Assistive products abandoned because of the demands of users are rarely considered during the design and development phases. Most rehabilitation equipment is technology driven rather than user driven, causing problems of accessibility and usability.[11–13] At the same time, many designers understand much less about the needs and requirements of users than the users themselves do. Therefore, by gathering information on user experience of utilizing the product, usage environment, preferences, and needs, it is possible to develop a product that meets user needs.[14,15]

Most previous studies on robotic hand rehabilitation devices focus on product technology adoption, particular functions of product description, or functional testing. Adamovich *et al.* integrated a CyberGlove, a Rutgers Master II-ND haptic glove, and a virtual-reality-based system to train the finger range of motion and finger strength.[16] Bae *et al.* proposed DULEX-II, which is a robotic orthosis having three degrees of freedom for assisting the motions of hand rehabilitation exercises.[17] Rong *et al.* noted that the electromyography-driven robot system integrated with neuromuscular electrical stimulation could improve finger movement accuracy.[18] The robotic hand rehabilitation device has independent actuation of each of the joints of each finger to enhance the flexion and extension of fingers.[19,20] Furthermore, the soft robotic glove contains flexible material and a mechanism to not only adjust the fit to the hand but also assist in finger grasping exercises. [21,22]

A few studies have been conducted on documenting the barriers and overall concepts related to robotic hand rehabilitation device access for hemiparetic patients.[10,14,15,23] However, the information contained in those studies is incomplete; for example, they do not cover the perspectives of people in different roles such as post-stroke patients, caregivers, and therapists, how the barriers are perceived, or the potential solutions for overcoming these barriers.

In view of the above, there is no comprehensive study on the needs and requirements of hemiparetic patients with regard to robotic hand rehabilitation devices at home. Therefore, in this study, a user-centered design approach is adopted to achieve the following objectives: (1) explore participants' experiences and expectations regarding hand rehabilitation devices at home, (2) identify user needs for home-based robotic rehabilitation devices for the hand, and (3) translate user needs into user requirements.

## 2. Materials and Methods

In this work, we apply qualitative research to develop a contextual and detailed understanding of the needs of hand rehabilitation device users with respect to their daily activities and rehabilitation at home. Interviews were also conducted to gather additional insights through the interactions of ideas and suggestions from the participants.[24] Observational research provided a reliable measurement of actual participant behavior within natural contexts.[25] The work was conducted in three phases, participant recruitment, data collection, and data analysis, as shown in Fig. 1. The details of each phase are described below.

### 2.1 User recruitment phase

Purposive sampling was employed to select post-stroke individuals, caregivers, and therapists. Recruitment continued until the point of theme saturation.[26] A sample of 28 participants (12 stroke survivors, 6 caregivers, and 10 therapists) was purposefully selected to participate in the study (see Table 1 for details). Written consent was obtained from all participants to ensure their rights and confidentiality. Before beginning the interview, the researcher explained the purpose of the study and obtained participants' permission to record audio and video during interviews and observations. At the same time, the researcher informed the participants that the audio and video data would be kept in a secure place during the study and erased afterwards, and that pseudonyms would be used to maintain participant anonymity with regard to the interview and observation results.

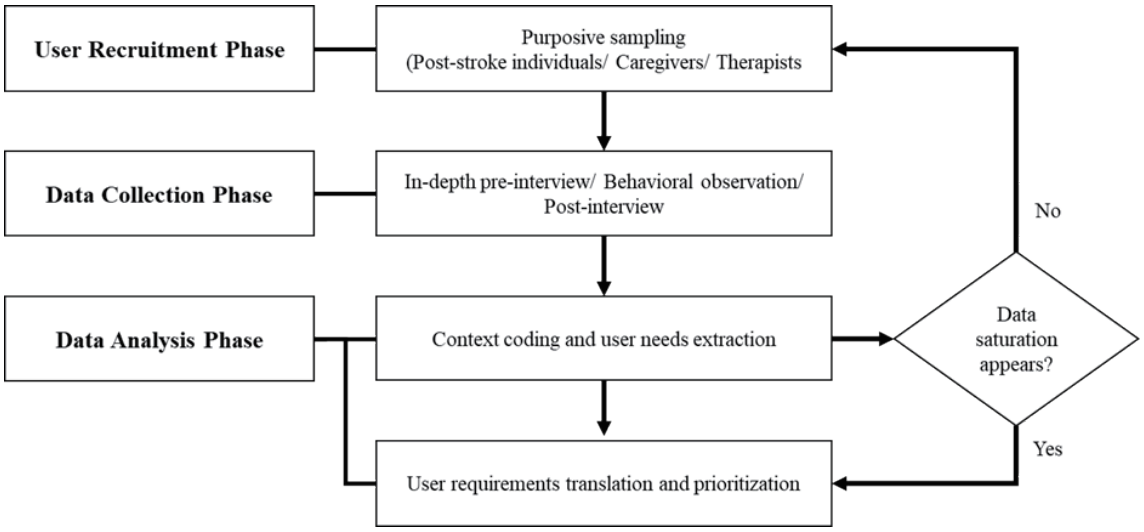


Fig. 1. Research process utilized in the study. The research process included user recruitment, data collection, and data analysis. User recruitment was halted once data saturation was reached.

Table 1
Profiles of post-stroke patients, caregivers, and therapists.

| Role | No. | Gender | Age | Time since stroke (yrs.) | Caregiver (Gender/Age) | Caregiver participated |
|---|---|---|---|---|---|---|
| Post-stroke patients | 1 | M | 53 | 3.7 | — | — |
| | 2 | M | 62 | 5.3 | Domestic helper (F/32) | — |
| | 3 | M | 49 | 0.6 | Wife (F/49) | Y |
| | 4 | F | 59 | 5 | Daughter (F/19) | — |
| | 5 | M | 45 | 2.9 | Wife (F/42) | — |
| | 6 | M | 68 | 3.7 | Wife (F/67) | Y |
| | 7 | F | 70 | 4.4 | Sister (F/68) | — |
| | 8 | M | 45 | 1.2 | Domestic helper (F/25) | — |
| | 9 | M | 47 | 0.9 | Wife (F/46) | Y |
| | 10 | M | 65 | 4.8 | Wife (F/65) | Y |
| | 11 | M | 58 | 2.1 | Wife (F/56) | Y |
| | 12 | F | 50 | 3.2 | Domestic helper (F/23) | Y |
| Role | No. | Gender | Age | Experience (yrs.) | | |
| Therapist | 1 | M | 53 | 24 | | |
| | 2 | F | 57 | 26 | | |
| | 3 | M | 34 | 10 | | |
| | 4 | M | 51 | 20 | | |
| | 5 | F | 43 | 18 | | |
| | 6 | M | 51 | 22 | | |
| | 7 | M | 51 | 23 | | |
| | 8 | M | 51 | 22 | | |
| | 9 | M | 35 | 6 | | |
| | 10 | M | 29 | 5 | | |

## 2.2 Data collection phase

The data collection methods included an in-depth pre-interview, behavioral observation, and post-interview. The hand rehabilitation technology experience questionnaire, Activities of Daily Living Questionnaire (ADLQ), and hand assessment and therapy questionnaire were used to collect subjective responses from the participants at the in-depth pre-interview stage.[27–29] Appendix A presents selected questions used in in-depth pre-interviews.

The aims of the one-to-one in-depth pre-interview were to elicit implicit issues encountered by the post-stroke patients while using the hand rehabilitation devices, survey the behaviors of the caregiver while helping post-stroke patients in daily life and during hand rehabilitation, and explore the concerns of the therapist while the post-stroke patient was performing rehabilitation exercises and using the hand rehabilitation devices at home. The pre-interview lasted approximately 60 min, and the questions were presented in a semi-structured questionnaire format. The interviews included general probes to elicit detailed information from participants. Probes, which are follow-up questions used to clarify statements made by participants during the interview, helped researchers address new issues raised in the interview process.[30] An example of a participant's responses to questions, subsequent probes, and responses to probes is shown in Table 2. Additionally, audio recordings were made of all pre-interview questions from the researchers and responses from the participants, and were later transcribed.

Table 2
Sample of raw data of interview questions, subsequent probes, and responses.

| | Sample text |
|---|---|
| Question: | Can you perform hand rehabilitation with hand rehabilitation devices by yourself, without assistance from others? |
| Response: | Not exactly. Sometimes I require assistance from my son or wife to set up or wear the devices. |
| Probe: | Could you provide some examples of hand rehabilitation devices that your son or wife assists you in set up or wear? |
| Response: | Similar to this dynamic hand orthosis, I am unable to straighten the fingers of the affected hand due to spasticity. Additionally, my unaffected hand lacks the strength to assist in straightening the fingers on the affected hand. Consequently, my son helps me by spreading and placing each finger into the finger rings. |
| Probe: | Can you adjust the tension of the wire and Velcro by yourself? |
| Response: | Yes, because it does not require much strength from the unaffected hand. |
| Probe: | Can you take off this dynamic hand orthosis by yourself? |
| Response: | Yes, taking off the orthosis is easier than putting it on. |

The participant observation method was used to observe the hand rehabilitation process, activities, and device use of the participants with stroke. We attempted to observe the post-stroke individuals using their hand rehabilitation devices in order to identify the explicit and implicit problems of using hand rehabilitation devices. The explicit problems observed when each participant performed the tasks were recorded.

The objectives of the post-interview stage were (1) to prioritize the importance of user requirements, (2) to verify the non-fulfillment of user requirements, and (3) to elicit the implicit requirements encountered when using current hand rehabilitation devices. We designed a five-point Likert scale to grade the user requirements of the robotic hand rehabilitation device for home-based therapy to achieve the objectives.

### 2.3 Data analysis phase

Both qualitative and quantitative methods were adopted in the analysis. Data obtained from responses to the robotic hand rehabilitation user requirements prioritization questionnaire was entered into IBM SPSS version 22. Descriptive statistics were utilized to describe the score and priority of user requirements. The qualitative analysis comprises context coding and the extraction of user needs. In the content coding process, each statement or perception was considered as an element or observation for content analysis. Additionally, the qualitative code information was further utilized to support user needs.

All the data acquired from in-depth pre-interviews were transcribed before being imported into Nvivo 12.0, a computer program for analyzing qualitative data. The researcher performed the code assignments subjectively. For instance, the first four answers to the first two questions presented in Fig. 2 were both coded as “Rehabilitation information and management”. “Rehabilitation information and management” was thus coded 84 times, giving it a frequency of 84. Table 3 summarizes the 15 different answers coded as “Rehabilitation information and management”. Although the study involved only 28 participants, the “Rehabilitation information

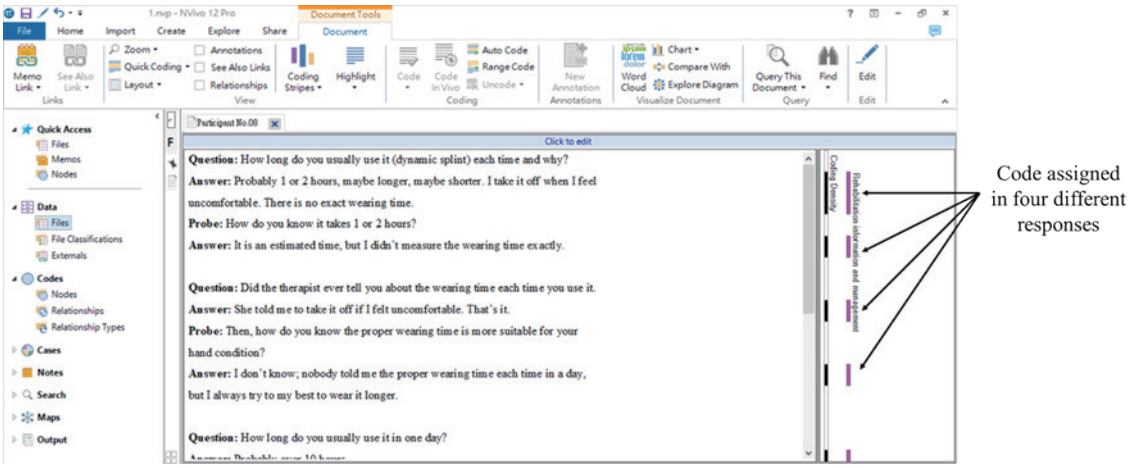


Fig. 2. (Color online) Example of a participant's response and code assignment.

Table 3
Sample of raw data from interviews supporting the qualitative codes.

| Code | Subcode | Sample raw data |
|---|---|---|
| Rehabilitation information and management | Automatic feedback and record | - It is an estimated time; I didn't measure the wearing time exactly.<br>- It can automatically record and display the results on the screen, so we don't need to count the number of completed tasks ourselves.<br>- Patients show me their rehabilitation task photos or videos.<br>- My wife always helps me to check the exercise time and count the number of repetitions achieved.<br>- I did not record the rehabilitation exercises that I performed.<br>- I can't remember all of my daily rehabilitation progress.<br>- I stop the rehabilitation exercises when I feel tired without recording the time.<br>- Sometimes, I use a timer to manage my rehabilitation sessions. |
| | Technical support | - Our son assists us in setting up and maintaining the digital device, as it involves numerous processes.<br>- I ask the store staff about how to use the rehabilitation equipment.<br>- Rehabilitation therapists demonstrate how to use the rehabilitation equipment.<br>- The robot orthosis at XX clinic requires multiple setup procedures. |
| | Customer service | - Many rehabilitation devices do not come with warranties.<br>- I prefer purchasing equipment from reputable rehabilitation equipment stores.<br>- The lack of after-sales service is highly frustrating. |

and management" code had a frequency higher than 28 because each participant gave the same response for different questions or probes. However, some codes may have frequencies lower than 28, because some participants gave no response to some questions or probes because they had no opinion or lacked knowledge relevant to the questions or probes. After all the data were coded, we grouped the codes into clusters and categorized them into themes on the basis of their attributes.

## 3. Findings

### 3.1 Role of participant vs hand rehabilitation

All stroke participants carried out the hand rehabilitation, which included continual physical and occupational therapy through the outpatient clinic at least twice a week in accordance with the national health insurance benefit following discharge from the hospital. The physical and occupational therapy took about 2 h each time. More than 50% of post-stroke participants had tried traditional Chinese treatments such as acupuncture and cupping therapy for hand rehabilitation. Six post-stroke participants had worn a static splint; two of them stopped wearing it owing to discomfort, and the other four used it rather haphazardly in terms of the time worn and the number of times of wearing it. Two post-stroke participants wore the dynamic splint while the hand was stiff and adjusted the tightness of the wires according to their feeling. A total of 75% of post-stroke participants used various hand grips and arm lift devices for rehabilitation exercises at home.

Over 70% of caregivers were family members. Caregivers provide support for stroke participants' daily activities of living, recovery, and rehabilitation. Sixty-seven percent of caregivers accompanied stroke patients to the outpatient clinic to assist in performing the rehabilitation exercises or equipment settings. The therapists conducted the hemiparetic assessment using tools (ADLs, Motor Assessment Scale, Modified Ashworth Scale, etc.), rehabilitation program planning and training, and assignments with rehabilitation equipment usage (hand skate, wooden stick board, cup stacking, etc.) each time the stroke participants attended the rehabilitation room. Also, the therapists assigned and confirmed post-stroke participants' home-based rehabilitation tasks. Usually, the therapists had to attend to more than two post-stroke participants at a time.

### 3.2 User needs of robotic hand rehabilitation device for home-based therapy

After all of the data were coded, it was then grouped subjectively on the basis of the attributes. Six groups of codes were identified for the user needs of a robotic hand rehabilitation device for home therapy, and each was assigned a unique need name: fundamental needs, ergonomics needs, emotional needs, accomplishment needs, policy support needs, and safety needs (as shown in Table 4). Taking into account the different levels of user capability and knowledge, the fundamental needs of robotic hand rehabilitation included rehabilitation information and a management system (such as automatic feedback and record, technical support, and customer service). For example, the following example interview transcript demonstrates the participant's fundamental needs (P = Patient; C = Caregiver; T = Therapist).

- *I tried the robotic hand rehabilitation device from the OO clinic, and it could automatically record and display the results on the screen. We don't need to count the number of finished tasks by ourselves. (P1)*

Table 4
Summary of user needs ($n$ = 28).

| User needs | Statements by Participants |
|---|---|
| Fundamental | Include appearances and a system that can help patients perform the rehabilitation exercises. |
| Ergonomics | Products must fit the human body and optimize human performance and cognitive functions. |
| Emotional | Provide ways of helping the post-stroke patient understand their emotions and feel connected and supported. |
| Accomplishment | Any kind of mechanism that can improve or encourage the patients' motivation for rehabilitation. |
| Policy | National laws governing the provision of rehabilitation. |
| Safety | The primary aim is to ensure patients' safety, including physical and personal information during and after using the rehabilitation equipment. |

- *If the rehabilitation device can trace and assess hand performance automatically, then I don't have to ask the therapist about my hand rehabilitation progress each time I go back to the hospital. (P6)*
- *Our son helps us to set up and maintain the digital device, since it involves a lot of different processes. (C10)*
- *I ask patients about the execution and challenges of home-based rehabilitation tasks every time they come here to do rehabilitation. Sometimes they show me their rehabilitation task photos or videos and want me to make sure their postures and steps are correct. (T2)*

Embedding ergonomic considerations into rehabilitation robots to cope with various patient demographic and anthropomorphic parameters is very important. Also, emotionalism can be annoying for people with a stroke and their families and can obstruct rehabilitation;[31] therefore, emotional needs should be taken care of along with the patients' physical therapy. A sense of accomplishment is a significant motivator for rehabilitation adherence.[32,33] Policy support capable of giving economic, physical, and psychological aid can reduce the family's financial stress and caregiver's stress. Safety is positively related to all other needs and is concerned with ensuring and providing safe mechanisms for people with stroke when using the rehabilitation robot at home. Equipment safety, environment safety, operation security, and personal information security were grouped together because they had the same attribute of "safety or security." At the same time, some indirect operational issues such as price, storage, and multiplace use influence patients' willingness to buy or use the device. The six needs categories were supported by all of the interviewers and at least 28 references for each category.

Because each user need category is closely linked to the other need categories, they were organized as shown in Fig. 3. Fundamental needs are basic user needs for the post-stroke hemiparetic patient and caregiver (and are thus at the center of the framework), since rehabilitation information feedback, technical support, and customer service could lead to acceptance of the assistive product.[9,13] Ergonomic design, emotional support, and feeling a sense of accomplishment are important parts of enhancing the willingness to use rehabilitation devices and motivation for post-stroke rehabilitation.[34,35] Policy support for a lack of family financial resources and insufficient knowledge of rehabilitation care are very important in long-term stroke care. The sample transcript below demonstrates the participants' responses to the relationships among the user needs of the robotic hand rehabilitation device for home-based therapy.

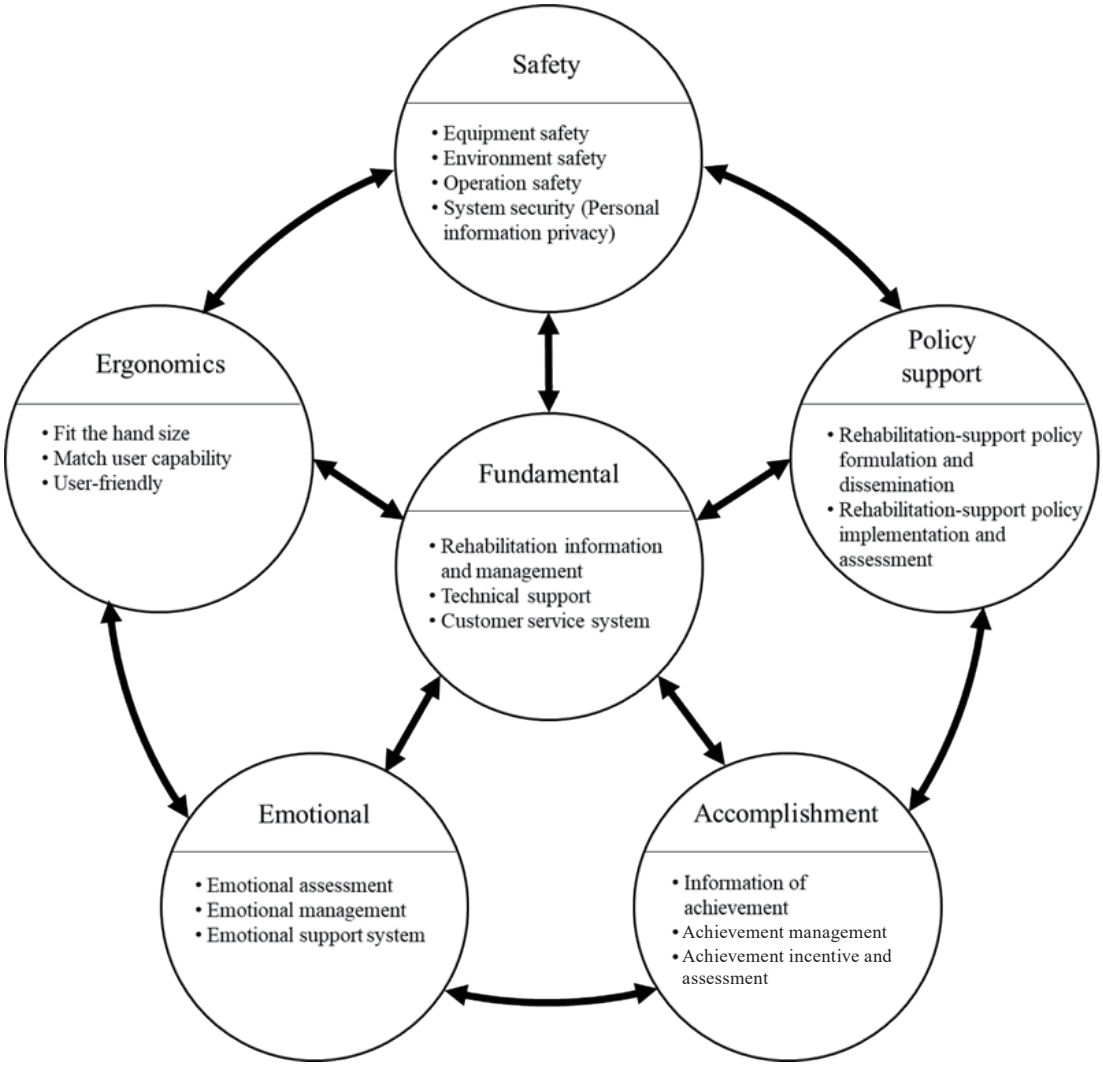


Fig. 3. Framework of user needs of robotic hand rehabilitation device for home-based therapy.

- *'Only this static splint is covered by National Health Insurance (Policy support), so the therapist measured my hand before making the splint (Ergonomics). Other rehabilitation devices were paid for by ourselves. They were not cheap and financially burdened my family (Others/Policy support), also, they might not fit my hand (Ergonomics).'... 'Most rehabilitation exercises are easy but boring (Accomplishment), just a repeat of a single movement'... 'My wife always helps me to check the exercise time and count the number of repetitions achieved (Fundamental).'... 'In the clinic, the therapists help to set up some of the rehabilitation devices because they are too complex (Fundamental/ Ergonomics).'... 'the device and operation safety are important (Safety), especially when I use it alone at home.'... 'the therapist, families, and friends always encourage and support me (Emotional), therefore, I have to work harder on rehabilitation, not only for myself but also for them.'*

### 3.3 User requirements of robotic hand rehabilitation device for home-based therapy

A requirement is a service, feature, function, or other elements of a product meeting user needs. Most users are uncertain of what they want and lack the assistance of a specialist to specify their requirements.[36,37] Therefore, the underlying user requirements must be presented in a format, such as a prototype or mock-up, that is easy for users to understand; then, they can provide feedback. However, the prototype and mock-up are focused on physical and nonphysical interface issues, which can be complex for users. Thus, we infer user requirements from interviews rather than directly asking participants their user requirements, and then the participants confirm the gleaned requirements.

On the basis of the definition of user requirements and the user needs framework, the six categories of needs were translated into user requirements (Table 5). For instance, the rehabilitation information and management system supports recording, analysis, and assessment of rehabilitation, allowing users to know their rehabilitation status and progress effectively and efficiently, and thus plan the next rehabilitation step. In addition, a need requires one or more

Table 5
User requirements of robotic hand rehabilitation device for home-based therapy.

| User needs | User requirements | Design justifications |
|---|---|---|
| Fundamental | Rehabilitation information and management | - The device supports recording, analysis, and assessment of rehabilitation status and progress. |
| | High reliability & stability | - The physical and nonphysical interface consistently performs well. |
| | Integrated system | - The system connects various rehabilitation devices through a network. |
| Ergonomics | Anthropometry<br>Wearing comfort<br>Light weight | - Soft material and an adjustable mechanism can improve the fit, benefitting finger grasp exercises and improving wear comfort. |
| | Easy to set up<br>Easy to put on & take off | - Fewer steps and proper guidance for setup, assembly, wearing, etc. |
| Emotional | Emotional assessment and management system | - The system helps to assess, calm, and express negative feelings. |
| | Information sharing<br>Interaction system | - The device can share the rehabilitation information with family, friends, and therapists, who can then respond. |
| Accomplishment | Real-time feedback & analysis of rehabilitation | - The rehabilitation status and progress can be displayed on a tablet, PC, or TV screen. |
| | Incentive mechanism<br>Gamification design | - Mechanism and design that are intended to shape and enhance the performance of rehabilitation, such as encouragement, score, level, ranking, etc. |
| Policy | Subsidy for equipment & therapist at home<br>Subsidy for caregiver | - An easy way to obtain subsidy information and apply for the subsidy. |
| | Health education | - Multiple ways of obtaining rehabilitation information. |
| Safety | Non–acute-angle design<br>Limit protection control<br>ID and password control<br>Permission setting | - The design aims to protect the physical and nonphysical safety of the user by incorporating mechanisms such as safety recovery and stop, buffering, safety verification, and so on. |

requirements that must be fulfilled, and conversely, a requirement can fulfill several needs. For example, easy to set up, assemble, and dissemble might be achieved by devising fewer steps or procedures.

### 3.4 Priority of user requirements of robotic hand rehabilitation device for home-based therapy

After six needs categories were translated into user requirements, we designed a five-point Likert scale to grade the user requirements of the robotic hand rehabilitation device for home-based therapy to prioritize the importance of user requirements (scale range from 1 to 5: 1 = not important, 5 = very important). The average of the requirements scores of user needs was over 3.5. The highest and lowest average scores of the user requirement of user needs were, respectively, limit protection control ($M$ = 4.7, $SD$ = 0.5) and gamification design ($M$ = 3.5, $SD$ = 0.7). The average sum scores of user requirements of each user need were over 3.8. The top three were safety needs ($M$ = 4.62, $SD$ = 0.01), ergonomic needs ($M$ = 4.42, $SD$ = 0.06), and fundamental needs ($M$ = 4.26, $SD$ = 0.18). The lowest was accomplishment needs ($M$ = 3.8, $SD$ = 0.25). The transcript below is an example of the participants' responses regarding the viewpoint of user requirements.

- *Safety is the most important thing, especially for me; I can't afford any harm to my body, therefore, the rehabilitation device should have a safety limit criterion such as maximum force to ensure safety during rehabilitation. (P3)*
- *He might wear the hand rehabilitation device for over four hours at a time, hence, a fit to his hand size and wearing comfort are necessary. (C4)*
- *If I can track my rehabilitation status and progress on the computer screen in real time, it would help in correcting and planning the rehabilitation exercises. (P2)*
- *I have to do the rehabilitation exercise even if I feel bored while doing those exercises, so if the rehabilitation exercises are a game, I would do the rehabilitation exercise more. (P5)*

## 4. Discussion

The six user needs of the robotic hand rehabilitation device for home-based therapy encompass not only device and system design, but also emotional and policy support. When assistive products match their users' needs, they enhance the user's rehabilitation, independence, and social participation.[38] On the contrary, unmet needs, barriers to use, and the lack of access to assistive products might hinder rehabilitation and result in a waste of public resources.

Safety is the most important consideration during rehabilitation device installation, operation, and maintenance. The robotic hand rehabilitation device must have an inbuilt proper safety mechanism such as safe actuation, suitable power mechanisms, and authority control to ensure user's physical and personal information safety.[39] In addition, anthropometry plays an important role in wearing a device that is designed to fit all users, is light weight, has flexible construction, and is adjustable to increase long-wearing comfort.[8,34] Difficulties in the interaction between the user, assistive product, and usage environment could lead to abandonment of the assistive product.

Moreover, providing real-time data for users to monitor real-time rehabilitation conditions is essential. The rehabilitation information record, analysis, and display help post-stroke individuals realize task execution performance and rehabilitation status. Neither the post-stroke user nor the caregiver wants to count the completion time or monitor whether a particular task has been achieved. At the same time, sharing real-time rehabilitation information with the therapist helps to understand and plan the rehabilitation. Financial problems due to medical bills or unemployment can occur, adding more stress to the post-stroke survivor and family. Therefore, government-subsidized rehabilitation care expenses for patients with stroke can reduce the financial burden on families. Additionally, stroke survivors will each have their own motivation, but a rehabilitation interface design with goal setting and game functions might encourage and motivate stroke survivors to continue their rehabilitation exercises.[23,40]

The user-centered approach focuses on user needs and perspectives. The benefits of the user-centered approach are primarily associated with the completeness of product functionality, increased product usefulness, and user satisfaction.[41] In this study, we applied qualitative research to extract the needs of the robotic hand rehabilitation device for home-based therapy after stroke. Both interviews and task observation were conducted to discover the explicit and implicit needs or issues encountered by users (post-stroke individual, caregiver, and therapist) when carrying out hand therapy with hand rehabilitation devices at home. The coded needs were then sorted into six categories (fundamental, ergonomics, emotional, accomplishment, policy support, and safety) and each user need category was found to be closely linked with the other categories. The requirement participants most care about is limit protection control, because "safety" is the most important consideration in assistive technology usage. Long-term wearing comfort and effective rehabilitation requirements indicate that participants also take their ergonomic needs seriously. They would appreciate a home-based hand rehabilitation device equipped with the requirement of accomplishment needs such as a gamification design. Finally, the requirements were compared with current designs of hand rehabilitation devices. The results revealed that current hand rehabilitation device designs do not fulfill users' needs and requirements.

## 5. Conclusions

In this study, we focused on identifying the needs and requirements of users regarding home-based hand rehabilitation devices. The findings can serve as a reference for the future development of such devices. However, further designs and testing are necessary to provide support in the development of design guidelines for home-based hand rehabilitation devices. In addition, the absence of a systematic and complete set of quantitative methods and tools enabling the measurement of rehabilitation performance is one of the major challenges facing the home-based rehabilitation research community. Thus, future work on developing a validated methodology for assessing the rehabilitation performance of home-based rehabilitation devices is necessary.

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## References

1 MOHW: https://www.nhi.gov.tw/mqinfo/Map_1.aspx?Type=Stroke&DAID=1884&List=4 (accessed December 2022).
2 MOHW: https://dep.mohw.gov.tw/nhic/lp-1665-116.html (accessed October 2022).
3 T. Bader: Int. J. Ther. Rehabil. **15** (2008) 83. https://doi.org/10.12968/ijtr.2008.15.2.28191
4 Y. Chen, K. T. Abel, J. T. Janecek, Y. Chen, K. Zheng, and S. C. Cramer: Int. J. Med. Inf. **123** (2019) 11. https://doi.org/10.1016/j.ijmedinf.2018.12.001
5 O. ayındır, G. Akyüz, and N. Sekban: Turk. J. Phys. Med. Rehabil. **68** (2022) 54. https://doi.org/10.5606/tftrd.2022.8705
6 J. Kim, W. Park, and J. Kim: Sens. Mater. **32** (2020) 981. https://sensors.myu-group.co.jp/article.php?ss=2628
7 C. C. Liu, W. L. Hu, C. K. Liang, and C. C. Hsu: Sens. Mater. **34** (2022) 3765. https://sensors.myu-group.co.jp/article.php?ss=4080
8 M. Almenara, M. Cempini, C. Gómez, M. Cortese, C. Martín, J. Medina, N. Vitiello, and E. Opisso: Disability Rehabil. Assist. Technol. **12** (2017) 84. https://doi.org/10.3109/17483107.2015.1079653
9 P. Bernocchi, C. Mulè, F. Vanoglio, G. Taveggia, A. Luisa, and S. Scalvini: Top Stroke Rehabil. **25** (2018) 114. https://www.tandfonline.com/doi/full/10.1080/10749357.2017.1389021
10 B. Chinembiri, M. Zhang, K. Shang, X. F. Zhang, and W. Chen: Top Stroke Rehabil. **28** (2021) 1. https://doi.org/10.1080/10749357.2020.1755815
11 A. Ommeren, L. C. Smulders, G. B. Prange-Lasonder, J. H. Buurke, P. H. Veltink, and J. S. Rietman: JMIR Rehabil. Assistive Technol. **5** (2018) e10510 https://doi.org/10.2196/10510
12 H. Pedersen, P. S. Kermit, and S. Söderström: Disability Rehabil. Assist. Technol. **16** (2021) 1. https://doi.org/10.1080/17483107.2020.1741702
13 A. T. Sugawara, V. D. Ramos, F. M. Alfieri, and L. R. Battistella: Disability Rehabil. Assist. Technol. **13** (2018) 16. https://doi.org/10.1080/17483107.2018.1425748
14 M. Hassenzahl: Encyclopedia of Human-Computer Interaction, M. Soegaard, and R. F. Dam, Eds. (Sage Publications, Thousand Oaks, 2011) 2nd ed., Chap. 3, pp. 63–112.
15 J. van der Linden, V. Waights, Y. Roger, and C. Taylor: Health Inf. J. **18** (2012) 212. https://doi.org/10.1177/1460458212442934
16 S. V. Adamovich, A. S. Merians, R. Boian, M. Tremaine, G. S. Burdea, M. Recce, and H. Poizner: Presence: Teleoperators and Virtual Environ. **14** (2004) 161. https://doi.org/10.1162/1054746053966996
17 J. Bae, Y. Kim, and I. Moon: 2012 4th IEEE RAS & EMBS Int. Conf. Biomedical Robotics and Biomechatronics (BioRob, 2012) 1482. https://doi.org/10.1109/BioRob.2012.6290736
18 W. Rong, K. Y. Tong, X. L. Hu, and S. K. Ho: Disability Rehabil. Assist. Technol. **10** (2013) 149. https://doi.org/10.3109/17483107.2013.873491
19 L. Cheng, M. Chen, and Z. Li: IEEE Access **6** (2018) 74039. https://doi.org/10.1109/ACCESS.2018.2884451
20 Y. Fu, Q. Zhang, F. Zhang, and Z. Gan: 2011 IEEE Int. Conf. Mechatronics and Automation (IEEE, 2011) 112. https://doi.org/10.1109/ICMA.2011.5985641
21 P. Panagiotis, Z. Wang, K. C. Gallowaya, R. J. Wood, and C. J. Walsh: Rob. Auton. Syst. **73** (2015) 135. https://doi.org/10.1016/j.robot.2014.08.014
22 D. Wang and H. Yu: Man-Machine-Environment System Engineering Conf. (MMESE, 2018) 151.
23 N. Nasr, B. Leon, G. Mountain, S. M. Nijenhuis, G. Prange, P, Sale, and F. Amirabdollahian: Assist. Technol. **11** (2016) 653. https://doi.org/10.3109/17483107.2015.1036469
24 C. Robson: Small-Scale Evaluation: Principles and Practice (SAGE Publications, London, 2017) 2nd ed.
25 M. Shipman: Educational Research: Principle, Policy, and Practices (Tylor & Francis. London, 1985) 1st ed.
26 J. M. Corbin and A. L. Strauss: Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory (SAGE Publications, Los Angeles, 2014) 4th ed.
27 P. F. Edemekong, D. L. Bomgaars, S. Sukumaran, and S. Caroline: Activities of Daily Living (StatPearls Publishing, Treasure Island, 2023). https://www.ncbi.nlm.nih.gov/books/NBK470404/

28 L. A. Legg, S. R. Lewis, O. J. Schofield-Robinson, A. Drummond, and P. Langhorne: Cochrane Database Syst. Rev. **7** (2017) CD003585. https://pubmed.ncbi.nlm.nih.gov/28721691/
29 M. E. Mlinac and M. C. Feng: Arch. Clin. Neuropsychol. **3** (2016) 506. https://pubmed.ncbi.nlm.nih.gov/27475282/
30 K. Baxter, C. Courage, and K. Caine: Understanding Your Users: A Practical Guide to User Research Methods (Morgan Kaufmann, Burlington, 2015) 2nd ed.
31 D. Sinyor, P. Amato, D. G. Kaloupek, R. Becker, M. Goldenberg, and H. Coopersmith: Stroke **17** (1986) 1102. https://doi.org/10.1161/01.str.17.6.1102
32 K. K. Miller, R. E. Porter, E. DeBaun-Sprague, M. V. Puymbroeck, and A. A. Schmid: Top Stroke Rehabil. **24** (2017) 142. https://doi.org/10.1080/10749357.2016.1200292
33 K. Atler: Disability Rehabil. **38** (2016) 781. https://doi.org/10.3109/09638288.2015.1061603
34 K. Serbest and O. Eldogan: J. Polytechnic **24** (2021) 305. https://doi.org/10.2339/politeknik.725310
35 N. Maclean and P. Pound: Soc. Sci. Med. **50** (2000) 495. https://doi.org/10.1016/s0277-9536(99)00334-2
36 S. Kujala: Behav. Inf. Technol. **22** (2003) 1. https://doi.org/10.1080/01449290301782
37 S. Kujala: Behav. Inf. Technol. **27** (2008) 457. https://doi.org/10.1080/01449290601111051
38 P. Johnston, L. M. Currie, D. Drynan, T. Stainton, and L. Jongbloed: Assist. Technol. **9** (2014) 421. https://doi.org/10.3109/17483107.2014.900574
39 C. Y. Chu, R. M Patterson, and J. Neuroeng: J. Neuroeng. Rehabil. **15** (2018) 9. https://doi.org/10.1186/s12984-018-0350-6
40 B. A. English and A. M. Howard: 2014 IEEE Int. Workshop Advanced Robotics and its Social Impacts (IEEE, 2014) 14. https://doi.org/10.1109/ARSO.2014.7020973
41 J. Ripat and A. Booth: Disabil. Rehabil. **27** (2005) 1461. https://doi.org/10.1080/09638280500264535


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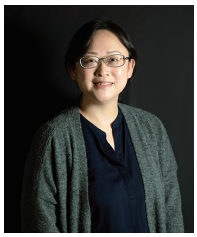

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## Appendix A: Select questions used in in-depth pre-interviews

| Post-stroke patient |
|---|
| Question: Why do you use this hand rehabilitation device? |
| Question: When do you use this hand rehabilitation device? |
| Question: Can you set it up by yourself? (If the device needs to be set up before use) |
| Probe for “no” response: What's the reason why you can't set it up by yourself? |
| Probe for “yes” response: How long do you usually take to set it up by yourself? |
| Question: Can you put it on by yourself? (If the device has to be worn on the hand before use) |
| Probe for “no” response: What's the reason why you can't wear it by yourself? |
| Probe for “yes” response: How long does it usually take you to put it on by yourself? |
| Question: Can you take it off by yourself? |
| Probe for “no” response: What's the reason why you can't take it off by yourself? |
| Probe for “yes” response: How long do you usually take to take it off by yourself? |
| Question: How long do you usually use it at a time and why? |
| Question: What is your opinion of the design of this hand rehabilitation device? |
| Probe: Why do you have that opinion? |
| Caregiver |
| Question: What daily activities do you assist her/him with? |
| Question: What do you do to help her/him accomplish this daily activity? |
| Question: Do you do the task because he/she can’t accomplish it alone? |
| Probe for “no” response: Why do you do the task if he/he can accomplish the activity alone? |
| Question: What do you do to help her/him do hand rehabilitation at the home and the clinic? |
| Question: Why do you help her/him do that? |
| Question: What else do you help her/him with? |
| Therapist |
| Question: Have you provided any tools to help post-stroke patients with the hand rehabilitation exercises at home? |
| Probe for “yes” response: What kind of tools and why? |
| Question: How do you know the post-stroke patient really did the hand rehabilitation exercises that you assigned to her/him at home? |
| Probe for “not sure” response: Then do you make sure or not? |
| Probe for “yes” response: How do you make sure or not? |
| Probe for “no” response: Why? |
| Question: How do you know the post-stroke patient did correctly the hand rehabilitation exercises that you assigned to her/him at home? |
| Probe for “not sure” response: Then do you make sure or not? |
| Probe for “yes” response: How do you make sure or not? |
| Probe for “no” response: Why? |
| Question: Do you have any problems with the post-stroke patient responding to you while he/she does the hand rehabilitation exercises at home? |
| Question: Do you have any problems with the post-stroke patient responding to you while using the hand rehabilitation device at home? |