*Review Article*

DIGITAL HEALTH

DIGITAL HEALTH
Volume 10: 1–22

DOI: 10.1177/20552076241237384
journals.sagepub.com/home/dhj
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# The most used questionnaires for evaluating the usability of robots and smart wearables: A scoping review

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## Abstract

**Background:** As the field of robotics and smart wearables continues to advance rapidly, the evaluation of their usability becomes paramount. Researchers may encounter difficulty in finding a suitable questionnaire for evaluating the usability of robotics and smart wearables. Therefore, the aim of this study is to identify the most commonly utilized questionnaires for assessing the usability of robots and smart wearables.

**Methods:** A comprehensive search of databases, including PubMed, Web of Science, and Scopus, was conducted for this scoping review. Two authors performed the selection of articles and data extraction using a 10-field data extraction form. In cases of disagreements, a third author was consulted to reach a consensus. The inclusions were English-language original research articles that utilized validated questionnaires to assess the usability of healthcare robots and smart wearables. The exclusions comprised review articles, non-English publications, studies not focused on usability, those assessing clinical outcomes, articles lacking questionnaire details, and those using non-validated or researcher-made questionnaires. Descriptive statistics methods (frequency and percentage), were employed to analyze the data.

**Results:** A total of 314 articles were obtained, and after eliminating irrelevant and duplicate articles, a final selection of 50 articles was included in this review. A total of 17 questionnaires were identified to evaluate the usability of robots and smart wearables, with 10 questionnaires specifically for wearables and 7 questionnaires for robots. The System Usability Scale (50%) and Post-Study System Usability Questionnaire (19.44%) were the predominant questionnaires utilized to assess the usability of smart wearables. Moreover, the most commonly used questionnaires for evaluating the usability of robots were the System Usability Scale (56.66%), User Experience Questionnaire (16.66%), and Quebec User Evaluation of Satisfaction with Assistive Technology (10%).

**Conclusion:** Commonly employed questionnaires serve as valuable tools in assessing the usability of robots and smart wearables, aiding in the refinement and optimization of these technologies for enhanced user experiences. By incorporating user feedback and insights, designers can strive towards creating more intuitive and effective robotic and wearable solutions.

## Keywords

Evaluation, assessment, usability, robots, wearables

Submission date: 15 May 2023; Acceptance date: 27 February 2024

## Introduction

The lack of usability in robots and smart wearables poses significant challenges that hinder their effective integration and adoption. Firstly, it hinders user adoption and acceptance, as complex interfaces and controls make these technologies difficult to operate for individuals without specialized knowledge or training. This leads to frustration and limited engagement with the devices.[1] Secondly, inadequate usability hinders the effortless assimilation of robots

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and wearables into daily routines, limiting the potential benefits and functionality of robots and wearables.[2] The lack of intuitive and natural interaction further restricts user engagement and hampers the overall user experience.[3] Moreover, poor usability can result in errors, inefficiencies, and decreased productivity, undermining the intended advantages of these technologies.[4] Overcoming these challenges is essential to unlock the full potential of robots and smart wearables, ensuring their effective utilization, and maximizing user satisfaction.[5] One of the ways to overcome these challenges is to evaluate the continuous usability of these technologies.

Assessing and measuring the usability of robots and smart wearables are crucial steps in understanding how well these technologies meet user needs and expectations.[6,7] To accomplish this, researchers and practitioners rely on questionnaires specifically designed to evaluate the usability of these devices.[6] These questionnaires serve as valuable tools for gathering user feedback, identifying areas for improvement, and enhancing the overall user experience. As far as we know, no study has been conducted to identify the most common usability evaluation questionnaires for robots and smart wearables. Only two studies have identified and introduced the most common questionnaires for evaluating telemedicine services,[8] as well as assessing satisfaction, acceptance, usability, and quality outcomes of m-health Apps.[9] Moreover, existing literature has diligently explored usability scores in digital health,[10] the usability of robots and smart wearables has remained a relatively underexplored frontier. The challenges posed by the lack of intuitive interaction and integration into daily routines are distinctive to these technologies and necessitate a specialized focus.[11] Meyer et al.,[6] highlighted the scarcity of dedicated studies evaluating the usability of robots and wearables, emphasizing the lack of clear evaluation tools and guidelines, despite the consensus on the importance of usability in user-centered design. Khakurel et al.,[7] noted that due to the relatively recent emergence of wearable devices as a field of study, there is a scarcity of research examining usability and usability evaluation tools and its correlation with various types of wearable technology. Conducting various studies to introduce usability evaluation tools, evaluation methods, standards, and metrics can be very helpful in this field.

Therefore, this scoping review endeavors to provide a comprehensive understanding of the most utilized questionnaires for evaluating the usability of robots and smart wearables. By illuminating this specific facet, our study offers novel insights that bridge a critical gap in the existing literature. Our study distinguishes itself from previous work in several ways. First, we focus specifically on robots and smart wearables, which have distinct usability characteristics compared to other digital health technologies. Second, we adopt a comprehensive scoping review methodology, ensuring a thorough examination of the available literature. Third, we provide a detailed analysis of the identified questionnaires.

Moreover, this scoping review not only contributes to the ongoing discourse on usability evaluations but also serves as a valuable resource for researchers, practitioners, and developers working in robotics and wearable technology. By providing a comprehensive overview of the most commonly used questionnaires, we assist in the selection and application of appropriate tools for usability assessment. Moreover, our findings pave the way for future research on usability evaluation methodologies, ultimately contributing to the development of more intuitive, user-friendly, and impactful robots and smart wearables.

## Material and methods

The Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) checklist was utilized in this study to ensure the selection of studies and proper reporting of the results (More details in Appendix A).

### *Information sources and search strategy*

To identify articles pertaining to questionnaires used for evaluating the usability of robots and smart wearables, a comprehensive search was conducted in three databases: PubMed, Web of Science, and Scopus, until May 30, 2023. To search these databases, relevant keywords related to robots, wearables, usability, and questionnaires were utilized. The following combinations of keywords were employed to locate relevant articles:

((Robots OR smart wearables OR wearable OR wearable devices OR wearable apparatus) AND (usability evaluation OR usability assessment) AND (questionnaire))

### *Inclusion and exclusion criteria*

In order to ascertain the inclusion of studies, we systematically applied predefined inclusion and exclusion criteria, detailed in Table 1. These criteria served as the basis for our selection process, ensuring a rigorous and transparent approach to study inclusion.

### *Paper selection*

In the initial stage, abstracts of all relevant articles were obtained from three databases, namely PubMed, Web of Science, and Scopus, and were imported into the EndNote X9 software by the author, KHM. Duplicate articles were subsequently eliminated from the dataset. Then, two authors (KHM, RM) independently reviewed all the retrieved papers based on their titles and abstracts. Subsequently, the same individuals evaluated the full text of the selected papers. In cases where disagreements arose, the opinion of another author (KB) was sought.

**Table 1.** Study inclusion and exclusion criteria summary.

| Criteria type | Inclusion criteria | Exclusion criteria |
|---|---|---|
| Study design | Original observational and interventional research articles using a valid and referenced questionnaire | Review articles |
| Language | English language publications | Non-English language publications |
| Topic focus | Usability evaluation of robots and smart wearables in the healthcare field | Studies not specifically addressing the usability of robots and smart wearables |
| Outcome evaluation | Valid and referenced questionnaire for usability assessment | Studies evaluating clinical outcomes |
| Questionnaire details | Articles with details about the questionnaires used | Articles lacking details about the questionnaires used |
| Questionnaire status | Valid and referenced questionnaire for usability evaluation of robots and smart wearables | Questionnaires that have not undergone validation and researcher-made questionnaires |

### Data extraction

The included articles were analyzed, and the following information was extracted: first author's name, year of publication, country of origin, study aim, target population, type of wearable, type of robot, sample size, sample size based on breakdown of male and female participants, intervention period, and the name of the questionnaire used.

### Quality appraisal

Using the 2018 version of the Mixed Methods Appraisal Tool (MMAT), authors RM and KHM independently conducted a comprehensive assessment of the studies.[12] Any disagreements between the original author were resolved through discussions with an additional author (KB) until a consensus was reached. The evaluation of studies was carried out in accordance with the MMAT criteria relevant to the chosen category. It is noteworthy that the most recent version of MMAT provides a descriptive quality assessment rather than a cumulative numerical score. In each study category, response options included "yes," "no," and "can't tell". The selection of "can't tell" signified insufficient information in the study to provide a definitive "yes" or "no" response.[13]

### Synthesis of results

After storing and managing the data in MS Excel for processing, one author (KHM) thoroughly reviewed the imported data, conducting tasks such as spell-checking and cell formatting to ensure accuracy and consistency. Descriptive statistics, specifically frequency and percentage calculations, were employed to summarize the collected data. The descriptive data derived from the findings of the included articles were meticulously organized into tables and figures based on thematic categorization. This approach facilitated the presentation of the review's findings and guided the study aims by KB and RM.

## Results

A total of 314 articles were initially retrieved for this study. After excluding duplicates, a careful review and assessment of the remaining 268 studies was conducted based on predefined inclusion and exclusion criteria. Ultimately, 50 articles met the criteria and were included in the study. The details of the search process and study selection are visually presented in Figure 1.

### Characteristics of the included studies

A comprehensive summary of the chosen articles is outlined in Table 2.

### Study distribution by year and country

As shown in Figure 2, the majority of the studies included in this study were conducted in Italy ($n = 6$ (wearables = 4, robots = 2), 12%) and United Kingdom ($n = 5$(wearables = 4, robots = 1), 10%) (More details in Table 2).

As shown in Figure 3, the majority of articles focusing on the most used questionnaires for evaluating the usability of robots and smart wearables were published in 2020 ($n = 11$),[22–29,52–54] 2021 ($n = 9$),[1,0–34,55–57] and 2022 ($n = 10$),[35–41,58–60] respectively (More details in Table 2).

In the studies related to the evaluation of smart wearables, the largest sample size was 110 people, consisting of 60

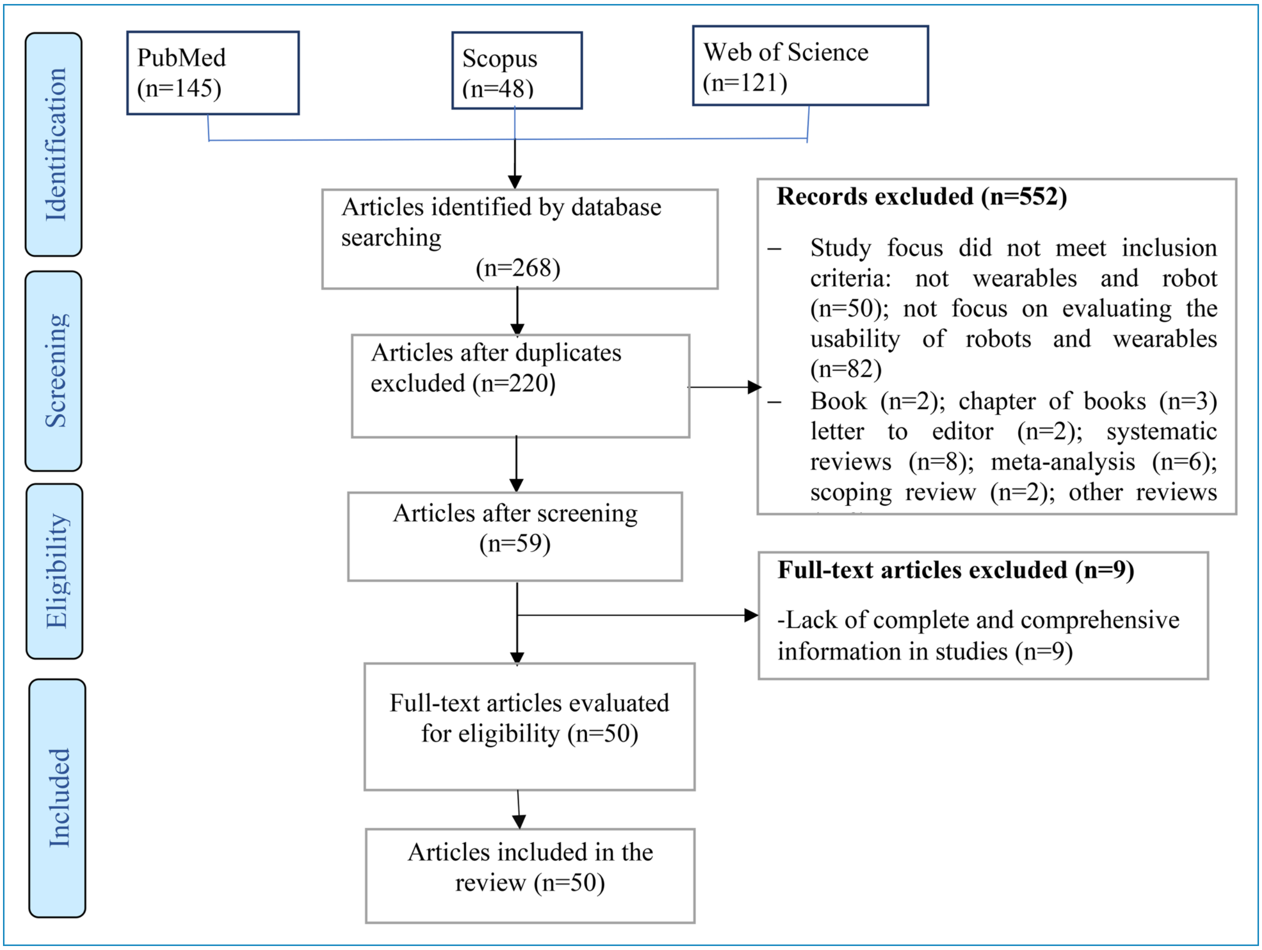


**Figure 1.** Study selection process.

women and 50 men.[40] Additionally, the smallest sample size in these studies included 4 people, comprising 2 women and 2 men.[18] In evaluating the usability of robots, the largest sample size in the studies included 1860 people, with 919 women and 941 men.[48] In evaluating the usability of robots, the smallest sample size in these studies included 5 people, with the participation rate of men and women varying in these studies[45,59,60] (More details in Table 2).

The minimum and maximum intervention time for evaluating the usability of wearables was 5 minutes[19] and 2 years,[30] respectively. In addition, the minimum and maximum intervention time for evaluating the usability of robots was 5 minutes[61] and 6 months,[52] respectively.

### Evaluation questionnaire

*The most frequently used questionnaires for evaluating the usability of smart wearables.* The questionnaires used to evaluate the usability of wearables are shown in Table 3. Ten questionnaires were identified to evaluate the usability of wearables. System Usability Scale (SUS) (50%), Post-Study System Usability Questionnaire (PSSUQ) (19.44%), Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST) (8.33%), and Mobile Application Rating Scale (8.33%) were the most used questionnaires.

*The most frequently used questionnaires for evaluating the usability of robots.* Seven questionnaires were identified for evaluating the usability of robots (Table 4). SUS (56.66%), User Experience Questionnaire (UEQ) (16.66%), and QUEST (10%) were the most used questionnaires for evaluating the usability of robots.

### Quality appraisal

The results of the studies' quality evaluation are outlined in Appendix B.

## Discussion

This paper presents an identification of the most prevalent and extensively employed questionnaires utilized for assessing the usability of robots and smart wearables. The SUS and PSSUQ have emerged as the primary questionnaires

Table 2.

| Ref | Country | Study aims | Target population | Wearable type | Sample size | Male | Female | Intervention period | Questionnaire name |
|---|---|---|---|---|---|---|---|---|---|
| **Wearable devices** | | | | | | | | | |
| 14 | Canada | Assessing the usability and wearability of a vibro-tactile display belt, designed to relay physiological information to anesthesiologists. | Anesthesiologists | Vibro-tactile display belt | 17 | 12 | 5 | 75 min per case | PSSUQ |
| 15 | Chicago | Evaluation of the usability of a tongue drive system by people with high-level spinal cord injury | People with high-level spinal cord injury | TDS | 11 | 9 | 2 | 6 weeks | PSSUQ |
| 16 | Portugal | Evaluating of a wearable system for home-based monitoring of Parkinson's symptoms | Patients with Parkinson | A wearable system for home-based assessment of Parkinson's symptoms | 22 | 14 | 8 | 12 weeks | PSSUQ |
| 17 | Switzerland | Evaluation of the applicability and usability of a wearable accelerometer device for the diagnosis of bilateral tonic-clonic seizures | Patients with bilateral tonic-clonic seizures | Wearable accelerometer device | 71 | 39 | 32 | 15 months | PSSUQ |
| 18 | Switzerland | Evaluation of adherence and acceptance of long-term use of a home-monitoring wearable by patients with Parkinson's disease | Patients with Parkinson's disease | Home-Monitoring wearable | 4 | 2 | 2 | 1-month | SUS |
| 19 | UK | Evaluation of usability, feasibility and acceptability of a wrist-worn activity tracker relapse in major depressive disorder | Patient with depressive disorder | wrist-worn activity tracker | - | - | - | 2-years | PSSUQ, and TAM-FF |
| 20 | South Korea | Usability analysis of FRAS | older people | wearable FRAS | 20 | - | - | 30 min | SUS, and MARS |

(continued)

**Table 2.** Continued.

| Ref | Country | Study aims | Target population | Wearable type | Sample size | Male | Female | Intervention period | Questionnaire name |
|---|---|---|---|---|---|---|---|---|---|
| **Wearable devices** | | | | | | | | | |
| 21 | Italy | Usability evaluation of a Smart Wearable for motion tracking for the upper limbs | Patients with Parkinson | Smart wearable for motion tracking for the upper limbs | 25 | 15 | 10 | 1-h | PSSUQ |
| 22 | Switzerland | Development And Evaluation Of A Wearable Skeleton For Wrist Extension/Flexion Support In Stroke Rehabilitation | Patients with stroke | Wrist exoskeleton | 17 | 10 | 7 | 1-week | SUS, and NASA-Task Load Index (RTLX) |
| 23 | Ireland | Comparing the usability of multiple wearable sensors by the older adult population | Older adults | Smart wearables to track physical activity | 8 | 5 | 3 | 1-week | IMI, and SUS |
| 24 | Netherlands | Identifying negative and positive effects as well as facilitators and barriers for the use of wearable device for monitoring of vital signs | Patients admitted to the internal medicine and surgical wards of the hospital | A wearable device for monitoring of vital signs | 100 | 60 | 30 | 45 min | SUS |
| 25 | UK | Evaluating the feasibility, usability, and acceptability of a wrist-worn device in remote assessment of disease and relapse in epilepsy | Patient with epilepsy | Wrist-worn device | - | - | - | 6-months | PSSUQ |
| 26 | Netherlands | Examining users' experiences and health related effects of exoskeleton in people with complete spinal cord injury | Patients with spinal cord injury | Wearable exoskeleton | 14 | 7 | 7 | 3-weeks | QUEST and SUS |
| 27 | UK | Assessing the feasibility and acceptability of utilizing an activity tracker for self-management of physical activity in patients with COPD | Patients with COPD | Activity tracker | 30 | 17 | 13 | Twice weekly for 6 to 7 weeks | SUS |

(continued)

**Table 2.** Continued.

| Wearable devices | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Ref | Country | Study aims | Target population | Wearable type | Sample size | Male | Female | Intervention period | Questionnaire name |
| 28 | Denmark | Evaluating a smart watch to assessment cognitive performance and check the usability of this tool | Patients with cognitive function disorders | Smartwatches | 21 | 12 | 9 | 60–75 min per participant | MARS |
| 29 | Denmark | This paper presents a study of two smartwatch-based cognitive tests to assess participants' attention and working memory. | Patients with cognitive function disorders | Smartwatch | 21 | 12 | 9 | Two min per participant | MARS |
| 30 | France | evaluation the user acceptability of a smart shoe insole by frail older adults | Older adults | Smart Shoe Insole | 9 | 3 | 6 | At least 5 min with a tolerance of 1 min | QUEST |
| 31 | UK | Developing and assessing the feasibility of a digital intervention based on ACT specifically designed for individuals diagnosed with GAD | Adults with a diagnosis of GAD | A paired wearable device is used to collect data on both physical activity and sleep continuity | 10 | 0 | 0 | 2-weeks | SUS |
| 32 | Netherlands | Examining the acceptability and usability of a wearable consisting of smartphone and smartwatch by 10 patients with aggressive behavior | Patients with aggressive behavior | A wearable consisting of smartphone and smartwatch | 10 | 9 | 1 | 2-week | SUS |
| 33 | Italy | Evacuating the upper limb functional improvement in muscular dystrophy patients through the use of both a passive and a semi-active device and comparing the impact of this technology on arm functionality | Patients with muscular dystrophy | Assistive system for arm functions improvement | 36 | 32 | 4 | 2-weeks (4 h per day) | SUS |

(continued)

**Table 2.** Continued.

| Wearable devices | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Ref | Country | Study aims | Target population | Wearable type | Sample size | Male | Female | Intervention period | Questionnaire name |
| 34 | Republic of Korea | Assessing the time-efficiency and feasibility of using a patchy-type 12-lead ECG measuring and transmitting device (P-ECG) by an EMT in an ambulance during patient transport | EMT | Patchy-type wireless 12-lead electrocardiogram | 18 | 14 | 4 | 15 min of education on 12-lead ECG and the devices and 10 min of practice | SUS |
| 35 | Republic of Korea | Design and evaluate an mHealth platform that includes a smartphone application synchronized with a wearable activity tracker and a web-based portal | Patients with peripheral artery disease | A wearable activity tracker | 7 | 4 | 3 | Seven days | SUS |
| 36 | France | Investigating the technical feasibility of monitoring stretching exercises by a humanoid robot trainer for chronic back pain | Patients with CLBP | Humanoid Robot Coach for CLBP | 27 | - | - | 4-weeks | SUS |
| 37 | Italy | Design and evaluation of a wearable exoskeleton for rehabilitation of post-stroke persons | Patients with stroke | Wearable exoskeleton | 5 | 5 | | 1-day | SUS |
| 38 | Spain | Assessing the safety, usability, personal experiences, user satisfaction, and effort expended following an exergame using a Wearable IVR device in individuals with PD | Patients with Parkinson | A wearable HMD to promote physical activity in patients with Parkinson's disease | 32 | 25 | 7 | Two sessions per person | SUS |

(continued)

**Table 2.** Continued.

| Wearable devices | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Ref | Country | Study aims | Target population | Wearable type | Sample size | Male | Female | Intervention period | Questionnaire name |
| 39 | Germany | Examining the impact of a comprehensive self-regulation intervention on moderate to vigorous physical activity and step count, utilizing commercially available activity trackers and evaluating the acceptance and usability of these devices | Older adults | Activity tracker | 80 | 33 | 47 | 21-days | TSQ-WT |
| 40 | Portugal | (1) Evaluating the usability, acceptability, and user satisfaction with the Activity tracker 2 in older adults; (2) examining the mediating effect of the usability on the relationship between user specifications and satisfaction; and (3) exploreing the moderating effect of user characteristics on the relationship between usability and user satisfaction | Older adults | Activity tracker | 110 | 50 | 60 | 2over 15 days | USEQ, and SUS |
| 41 | France | Assessing Usability, User Experience (UX), Patients' Perceptions of Body Worn Sensors (BWS) and Health Care Providers' Opinions on BWS Monitoring | Patients with Parkinson | Body-Worn Sensors (BWS) for continuous assessment of patients with Parkinson motor symptoms | 22 | 9 | 13 | A week (30–60 min) | SUS |
| 42 | Italy | Evaluating usability of and satisfaction with Finger-size wearable assistive technology device for visually impaired | Visually impaired people | Finger-size wearable assistive technology device | 100 | 51 | 49 | 6-months | SUS, and QUEST |

(continued)

**Table 2.** Continued.

| Wearable devices | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Ref | Country | Study aims | Target population | Wearable type | Sample size | Male | Female | Intervention period | Questionnaire name |
| **Robots** | | | | | | | | | |
| Ref | Country | Study aims | Target Population | Robot type | Sample size | Male | Female | Intervention period | Questionnaire name |
| 43 | Italy | Design and evaluation of an assistive device for upper limb support | People with severe neuro-motor disabilities | Robotic exoskeleton arm | 6 | 5 | 1 | A single day session | TSQ-WT, and SUS |
| 44 | UK | Evaluation of human-robot interaction in a natural environment | - | Assistive robot to interact with humans | 12 | 8 | 4 | Once a week for a period of 10 weeks | SUS |
| 45 | Netherlands | Evaluation of a rehabilitation robot for upper limb disabilities | Patient with upper extremity disability | Rehabilitation robot | 5 | 4 | 1 | 6-weeks, 3 days per week, 60 min per day | SUS |
| 46 | Spain | Design and evaluation of a robot-based tool for physical and cognitive rehabilitation | Older people | A robot-based tool for physical and cognitive rehabilitation | 7 | - | - | Once every 3 months (duration of the session: 25 min) | SUS |
| 47 | Belgium | Investigating the motivation and expectations of stroke patients and therapists regarding the usability of robot-assisted walking training | Stroke patients | Robot-assisted gait rehabilitation | 46 | 26 | 20 | A week for approximately 30–45 min | Usefulness, Satisfaction and Ease of Use Questionnaire (USE) |
| 48 | Germany | Evaluation of automated real-time feedback provided by an on-shoe inertial sensor-based gait system in people with gait disorders after incomplete spinal cord injury, stroke and in the elderly. | Patients with gait disorders | Shoe-mounted inertial-sensor-based gait therapy system | 1860 | 919 | 941 | 4-weeks | QUEST |

(continued)

**Table 2.** Continued.

| Wearable devices | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Ref | Country | Study aims | Target population | Wearable type | Sample size | Male | Female | Intervention period | Questionnaire name |
| 49 | Canada | Comparing the effectiveness of two feedback approaches, Scores + Visual + Force feedback and Visual + Force feedback, in reducing trunk compensation | Hemiparetic stroke survivors | Rehabilitation robotic arms | 14 | 8 | 6 | - | SUS |
| 50 | Poland | Evaluation of the clinical applicability of a robotic assistant for patients with mild cognitive impairment and Alzheimer's | Patients suffering from MC) and AD | Robotic assistant for aging patients with memory impairments | 18 | 6 | 12 | - | UEQ |
| 51 | Germany | Comparing the usability, acceptability, and barriers of usage of a robot-supported gait rehabilitation system between younger group and an older group | Patients with gait impairments | Robot-supported gait rehabilitation system | 13 | 11 | 2 | Five-therapy sessions, each lasting 20 min | SUS |
| 52 | Italy | Evaluation of usability, and acceptance of a robotic walker from the perspective of patients and clinical professionals | Patients with walking disorders | Robotic walker | 42 | 20 | 22 | 6 months | SUS, and UEQ |
| 53 | USA | Identification and determination of barriers related to the use of an exoskeleton to reduce musculoskeletal symptoms for workers in the operating room | Workers in the OR | Surgical exoskeleton | 14 | 8 | 6 | 10-min | SUS |
| 54 | Canada | Evaluation of robotic gloves related to improvement of hand function in daily tasks of life after stroke | Patients with hand disability | Robotic glove | 9 | - | - | Single session of 2 h | QUEST, and USE |

(continued)

**Table 2.** Continued.

| Ref | Country | Study aims | Target population | Wearable type | Sample size | Male | Female | Intervention period | Questionnaire name |
|---|---|---|---|---|---|---|---|---|---|
| **Wearable devices** | | | | | | | | | |
| 1 | Canada | Evaluating the usability of a soft robotic glove for hand rehabilitation after stroke | Patients with hand disability | Soft robotic glove | 14 | 10 | 4 | 60-to-90-min | SUS |
| 55 | India | Designing and evaluating the usability of a hand rehabilitation | Patients with hand disability | Hand rehabilitation robot | 45 | - | - | Two-session training with the robot | SUS, and UEQ |
| 56 | Spain | Evaluation of usability of MERLIN robotic system based on serious games for upper limb rehabilitation in stroke patients | people with stroke | Rehabilitation robot | 9 | 6 | 3 | 3-sessions of 30 min | SUS, IMI, QUEST, and ArmAssist Usability Assessment Questionnaire |
| 57 | Spain | Exploring the usability, acceptability, and adoption of a hybrid exoskeleton or robot designed for passive rehabilitation of the upper limbs | Patients with upper limp disabilities | Hybrid exoskeleton or robot for upper limb rehabilitation | 7 | 1 | 6 | - | SUS |
| 58 | France | Development of a new gait rehabilitation device using RAGT and fully immersive VR evaluation of its usability | People with movement impairment and mild cognitive deficit | RAGT | 18 | 5 | 13 | 20-min with 24 h separating the two sessions | SUS |
| 59 | Colombia | Design and evaluation of lower limb rehabilitation robot | Patients with lower limb disabilities | Lower limb rehabilitation robot | 5 | 2 | 3 | - | SUS |

(continued)

**Table 2.** Continued.

| Wearable devices | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Ref | Country | Study aims | Target population | Wearable type | Sample size | Male | Female | Intervention period | Questionnaire name |
| 60 | Switzerland | Evaluation the technical usability and feasibility of an interactive leg-press training robot | Children with neuromuscular impairments | Interactive leg press training robot | 5 | 4 | 1 | Between 40 and 45 min | SUS |
| 61 | Portugal | Usability evaluation of a upper-limb rehabilitation robot | Patient with upper-limb disabilities | Upper-limb rehabilitation robot | 31 | - | - | 5-min | SUS and UEQ |
| 62 | Germany | Investigating factors affecting user experience in robot-assisted health monitoring systems by combining subjective and objective health data | Patients' caregivers | Robot-assisted health monitoring | 8 | - | - | Three sessions (30 and 60 min) | SUS and UEQ |

SUS: System Usability Scale; PSSUQ: Post-Study System Usability Questionnaire; UEQ: User Experience Questionnaire; QUEST: Quebec User Evaluation of Satisfaction with Assistive Technology; MARS: Mobile Application Rating Scale; TDS: Tongue Drive System; TAM-FF: Technology Assessment Model Fast Form; FRAS: fall risk assessment system; IMI: Intrinsic Motivation Inventory; COPD: chronic obstructive pulmonary disease; ACT: acceptance and commitment therapy; GAD: generalized anxiety disorder; EMT: emergency medical technician; CLBP: chronic low back pain; IVR: immersive virtual reality; PD: Parkinson's disease; HMD: head-mounted display; TSQ-WT: Tele-healthcare Satisfaction Questionnaire for Wearable Technology; USEQ: User Satisfaction Evaluation Questionnaire; MCI: mild cognitive impairments; AD: Alzheimer Disease; OR: operating room; RAGT: robot-assisted gait training; VR: virtual reality; RAGT: A robot-assisted gait training.

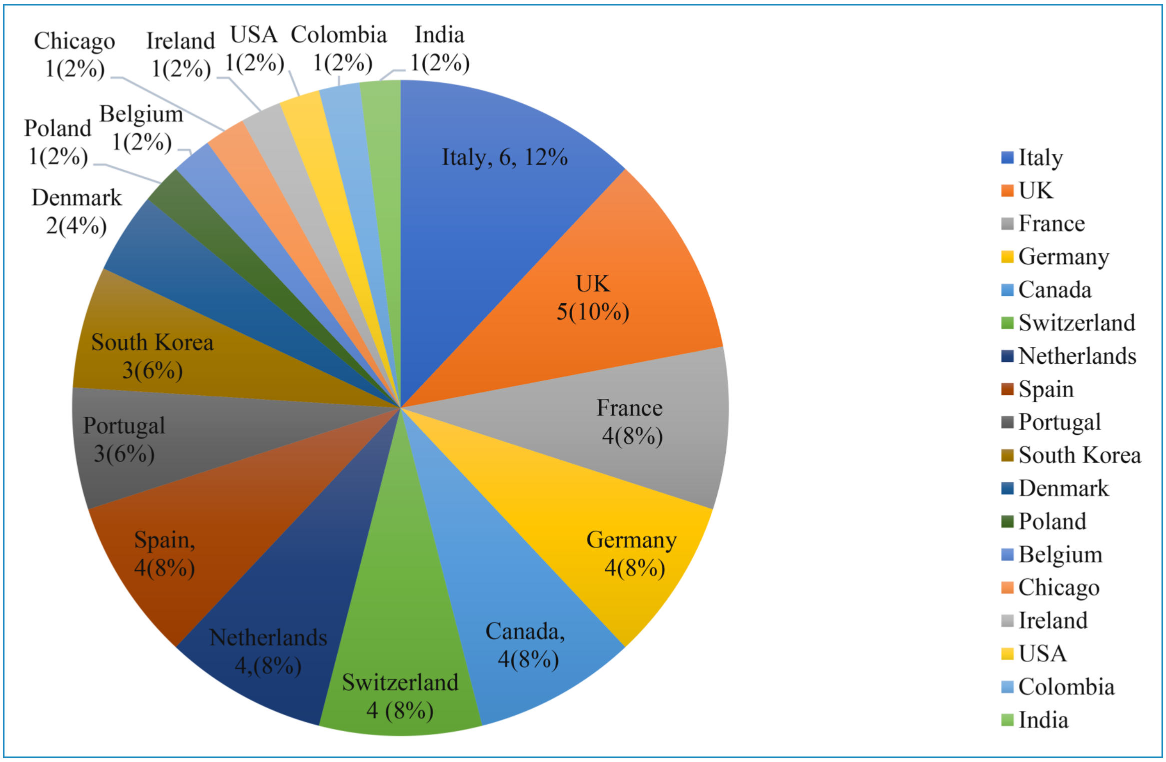


**Figure 2.** Distribution of the studies based on country.

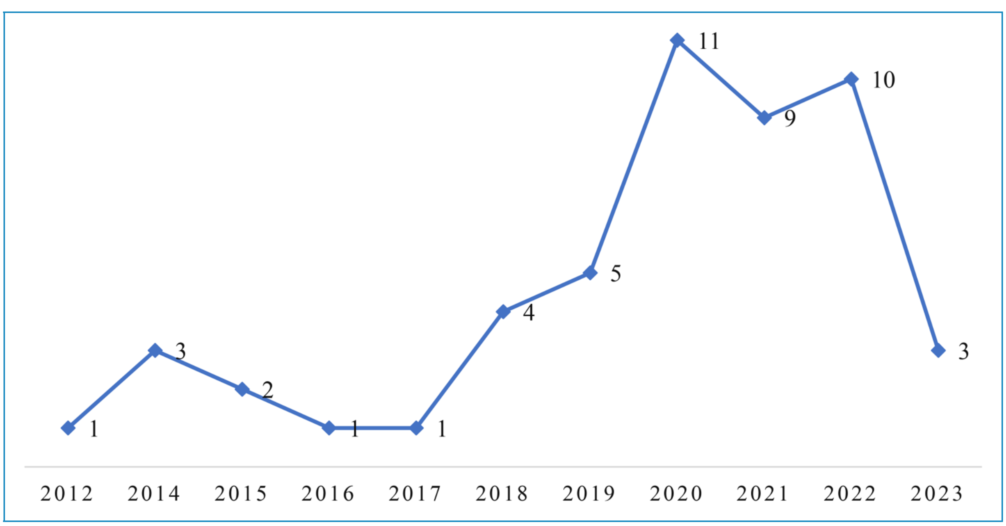


**Figure 3.** Distribution of the studies in terms of publication year.

used to assess the usability of smart wearables. Additionally, SUS, UEQ, and QUEST have been identified as the prevailing questionnaires employed to evaluate the usability of robots.

In the review conducted by Hajesmaeel-Gohari et al.,[9] the SUS and PSSUQ emerged as two commonly used questionnaires to assess satisfaction, usability, acceptance, and quality outcomes in the field of mobile health. According to their beliefs, the SUS is a widely used questionnaire for assessing the usability of electronic systems. In comparison to other questionnaires like CSUQ, SUS is considered a faster tool for evaluating perceived usability, as it contains fewer items and a simpler scale. Additionally, the SUS questionnaire includes a satisfaction question, which is often evaluated separately in dedicated satisfaction assessment tools but is encompassed within the usability evaluation. Due to

**Table 3.** The most frequently used questionnaires for evaluating the usability of smart wearables.

| Row | Questionnaire name | Ref | Frequency (%) | Description of the questionnaire |
|---|---|---|---|---|
| 1 | SUS | 18, 20, 22–24, 26, 27, 31–38, 40–42 | 18(50) | The SUS questionnaire was developed by Brooke et al. as a tool for evaluating the usability of electronic systems. It consists of ten items that are not categorized specifically. The items are rated on a 5-point Likert scale. The SUS questionnaire has been found to exhibit a high level of reliability, with a coefficient alpha of 0.91[63, 64]. |
| 2 | PSSUQ | 14–17, 19, 21, 25 | 7(19.44) | The PSSUQ was developed by Lewis as a means to evaluate user satisfaction with system usability at the conclusion of a study. The latest version of the questionnaire comprises 16 questions categorized into three sections: system usefulness, information quality, and interface quality. These questions are rated on a 7-point Likert scale. The criterion validity of the PSSUQ has demonstrated a moderate correlation ($r = 0.80$) with other measures of user satisfaction. Additionally, the PSSUQ exhibits strong reliability, with a coefficient alpha of 0.96 [64, 65]. |
| 3 | QUEST | 26, 30, 42 | 3(8.33) | The QUEST is a comprehensive assessment tool that evaluates user satisfaction with assistive technology, focusing on two key components: Device and Services. Rigorous psychometric testing has been conducted to examine its test-retest stability, alternate-form equivalence, internal consistency, factorial composition, and nomological validity. It consists of various items that focus on measuring users' opinions and experiences related to the effectiveness, ease of use, and overall satisfaction with the assistive technology they are utilizing [66]. |
| 4 | MARS | 20, 28, 29 | 3(8.33) | The MARS was introduced by Stoyanov et al. as a tool specifically designed to evaluate the quality of mobile health applications. This questionnaire consists of 23 items, categorized into six sections: engagement, functionality, aesthetics, information quality, subjective quality, and an app-specific section. The items in MARS are rated on a 5-point scale [67]. The construct validity of MARS was confirmed through confirmatory factor analysis, yielding favorable results (root mean square error of approximation = 0.074, Tucker–Lewis index = 0.922, confirmatory fit index = 0.940, standardized root mean square residual = 0.059). Furthermore, the reliability of the tool was verified with an Omega coefficient ranging from 0.79 to 0.93. In terms of concurrent validity, MARS demonstrated a significant correlation with ENLIGHT ($p < 0.05$), further supporting its validity as a measure for evaluating mobile health applications [68]. |
| 5 | IMI | 23 | 1(2.77) | The IMI is a questionnaire designed to assess an individual's intrinsic motivation, which refers to the internal drive and enjoyment derived from engaging in a particular activity. The IMI consists of several subscales that measure different aspects of intrinsic motivation, such as interest/enjoyment, perceived competence, effort/importance, value/usefulness, and pressure/tension. By capturing these dimensions, the IMI provides insights into the underlying factors that influence an individual's motivation to engage in a specific task or activity [69]. |
| 6 | TAM-FF | 19 | 1(2.77) | The TAM-FF questionnaire (Davis, 1989) is a concise tool designed to evaluate users' perceptions and attitudes towards technology. It assesses key dimensions such as perceived usefulness and perceived ease of use, which are crucial factors in determining individuals' acceptance and adoption of technology. The TAM-FF questionnaire provides a quick and efficient means of gathering data on users' perceptions, making it suitable for studies where time is limited [70]. |

(continued)

**Table 3.** Continued.

| Row | Questionnaire name | Ref | Frequency (%) | Description of the questionnaire |
|---|---|---|---|---|
| 8 | TSQ-WT | 39 | 1(2.77) | The TSQ-WT is a specialized questionnaire designed to assess user satisfaction with wearable technology used in tele-healthcare settings. It focuses on measuring user satisfaction with various aspects of wearable technology, including ease of use, functionality, reliability, and overall satisfaction with the tele-healthcare experience [39]. The TSQ-WT provides valuable insights into users' perceptions and experiences with wearable technology, enabling researchers and practitioners to identify strengths, weaknesses, and areas for improvement in tele-healthcare interventions. TSQ-WT comprises six dimensions that assess different aspects of user satisfaction, including benefit, usability, self-concept, privacy and loss of control, QoL, and wearing comfort of the system. Each dimension consists of five items that user's rate on a 5-point Likert scale, ranging from 0 to 4 points. Higher scores on the scale indicate more positive ratings, reflecting a greater level of satisfaction with the specific dimension being measured in the questionnaire [71]. |
| 9 | NASA TLX | 22 | 1(2.77) | The NASA TLX questionnaire is a widely used tool for assessing subjective workload and mental demands experienced by individuals during a task. It measures workload across six dimensions, including mental demand, physical demand, temporal demand, performance, effort, and frustration. Participants rate each dimension on a scale from 0 to 100, indicating the perceived level of workload or demand. The TLX questionnaire provides valuable insights into the cognitive and physical demands placed on individuals during various tasks, allowing researchers and practitioners to evaluate and compare workload across different conditions or interventions [72]. |
| 10 | USEQ | 40 | 1(2.77) | The USEQ is a questionnaire designed to assess user satisfaction with a specific product, service, or system. It aims to capture users' perceptions, opinions, and overall satisfaction regarding their experience. The USEQ typically consists of multiple items or statements that users rate on a scale, reflecting their level of satisfaction. The questionnaire covers various dimensions such as usability, functionality, aesthetics, and overall satisfaction. The USEQ is a reliable tool for measuring user satisfaction, as its psychometric properties have been thoroughly tested and validated. Its reliability ensures consistent and accurate measurement of user satisfaction, allowing researchers and practitioners to gather valuable insights for improving the design, usability, and overall quality of the product or service under evaluation. The USEQ, consisting of six items, demonstrated significant associations among them, indicating internal consistency. The Cronbach's alpha coefficient for the questionnaire was calculated to be 0.716, indicating a moderate level of reliability [73]. |

SUS: System Usability Scale; PSSUQ: Post-Study System Usability Questionnaire; MARS: Mobile Application Rating Scale; IMI: Intrinsic Motivation Inventory; TAM-FF: Technology Assessment Model Fast Form; TSQ-WT: Tele-healthcare Satisfaction Questionnaire for Wearable Technology; QoL: quality of life; TLX: Task Load Index; USEQ: User Satisfaction Evaluation Questionnaire.

**Table 4.** The most frequently used questionnaires for evaluating the usability of robots.

| Row | Questionnaire name | Ref | Frequency (%) | Description of the questionnaire |
|---|---|---|---|---|
| 1 | SUS | [1, 43–46, 49, 51–53, 55–62] | 17(56.66) | Table 3 provides a comprehensive overview of the questionnaire's description. |
| 2 | UEQ | [50, 52, 55, 61, 62] | 5(16.66) | The UEQ was introduced by Laugwitz et al.[74], as a tool for evaluating usability and user satisfaction. The questionnaire consists of items categorized into six sections: attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty. The items in this questionnaire are rated using a 7-point scale. The factor analysis of the UEQ demonstrated satisfactory validity, indicating that the questionnaire measures the intended constructs effectively. Additionally, the reliability of the UEQ was confirmed through Cronbach's alpha analysis, which exceeded 0.71, indicating strong internal consistency [74]. |
| 3 | QUEST | [48, 54, 56] | 3(10) | Table 3 provides a comprehensive overview of the questionnaire's description. |
| 4 | USE | [47, 54] | 2(6.66) | The USE questionnaire was developed by Lund et al. as a tool for assessing the usability of a system's user interface. This questionnaire consists of 30 items divided into four sections: usefulness, ease of use, ease of learning, and satisfaction. The items are rated on a 7-point Likert scale [75]. The validity of the USE questionnaire was demonstrated by the high correlations between its dimensions and the SUS, with correlation coefficients ranging from 0.60 to 0.82 ($p < 0.001$). These findings indicate that the USE questionnaire effectively measures usability. Additionally, the reliability of the USE questionnaire has been confirmed with a high Cronbach's alpha coefficient of 0.98, indicating strong internal consistency[75]. |
| 5 | IMI | [56] | 1(3.33) | Table 3 provides a comprehensive overview of the questionnaire's description. |
| 6 | TSQ-WT | [43] | 1(3.33) | Table 3 provides a comprehensive overview of the questionnaire's description. |
| 7 | ArmAssist Usability Assessment Questionnaire | [56] | 1(3.33) | The ArmAssist Usability Assessment Questionnaire is a specific questionnaire designed to evaluate the usability of the ArmAssist device. It assesses various usability dimensions, including ease of use, learnability, efficiency, effectiveness, and user satisfaction. The questionnaire comprises 17 survey items and is specifically tailored for use with the AA device, which is utilized in the MERLIN system. Participants, including patients and therapists, rate the questions on a scale of 1 (strongly agree) to 7 (strongly disagree), providing feedback on their satisfaction with the system and therapy. Additionally, the questionnaire includes three open-ended questions that allow participants to share their subjective opinions, such as the aspects they liked the most, identified negative aspects, and proposals for system improvement[56]. |

SUS: System Usability Scale; UEQ: User Experience Questionnaire; QUEST: Quebec User Evaluation of Satisfaction with Assistive Technology; USE: Usefulness, Satisfaction, and Ease of Use Questionnaire; IMI: Intrinsic Motivation Inventory; TSQ-WT: Tele-healthcare Satisfaction Questionnaire for Wearable Technology.

its features, reproducibility, reliability, and validity, researchers and evaluators of mHealth services frequently employ the SUS questionnaire,[9] Kaya et al.,[76] also asserted that the SUS incorporating an adjective scale rating stands out as a widely embraced and user-friendly questionnaire for assessing the usability of various products. This approach offers a straightforward score calculation, providing a comprehensive snapshot of a product's usability. Other studies also demonstrate that, with its straightforward scoring system, SUS facilitates efficient and rapid administration, rendering it a cost-effective option for usability testing.[77] The questionnaire's enduring presence in usability evaluation enables longitudinal comparisons, and its established credibility within the field enhances the trustworthiness of the insights it generates.[78] The assertion by Kaya et al.,[76] further solidifies SUS as a user-friendly and versatile tool for assessing various product usability. Additionally, the findings of other studies affirm SUS's efficiency in terms of scoring, administration, and cost-effectiveness, while its enduring presence allows for meaningful longitudinal comparisons. Overall, the extensive support from multiple studies underscores the credibility and utility of the SUS questionnaire in providing valuable insights for usability evaluations and beyond. It is recommended that future research explores potential enhancements or adaptations to further optimize its applicability in evolving technological landscapes.

Moreover, PSSUQ provides a comprehensive assessment of system usability, capturing users' perceptions of different aspects such as efficiency, learnability, and satisfaction, allowing for a holistic evaluation. The questionnaire is a well-established and validated tool, ensuring reliable and valid results, providing accurate insights into the usability of the system.[9] The study by Vlachogianni and Tselios,[79] shows that the comprehensive assessment approach of PSSUQ, covering efficiency, learnability, and satisfaction, ensures a thorough understanding of the user experience with these devices. Moreover, the PSSUQ is designed to be a practical and efficient tool, requiring users to respond to a limited number of items, making it feasible for use in various research and evaluation settings, enabling timely and valuable usability feedback.[9,64,65] Researchers and designers can rely on these questionnaires to obtain reliable and comparable usability data for smart wearables, enabling them to make informed decisions regarding improvements or optimizations. Moreover, in different studies,[80] the utility of PSSUQ is particularly emphasized in the context of smart wearables, where researchers and designers can depend on its reliability to obtain comparable usability data. Additionally, researchers and smart wearable device designers can depend on PSSUQ to obtain reliable and comparable usability data, enabling informed decision-making for improvements or optimizations. Moreover, PSSUQ's adaptability allows for exploration of potential refinements, ensuring its continued applicability and relevance in the ever-evolving landscape of smart wearables. As future developments in smart wearable technology unfold, it is recommended that researchers explore potential refinements or adaptations to ensure the continued applicability and relevance of PSSUQ in evolving technological landscapes.

Additionally, as emphasized in the study, the importance of the SUS, UEQ, and QUEST becomes evident when assessing the usability of robots. These questionnaires have emerged as the prevailing choices among researchers and practitioners, emphasizing their suitability and reliability in assessing the usability aspects specific to robotics.[8,9] SUS simplicity and efficiency make it a widely adopted tool, particularly valuable for assessing user experiences with robotic systems. The standardized nature of SUS enables consistent and comparable evaluations across different robots, fostering reliable insights into their usability.[46,59,60,62] Hesen[81] believed that, with a concise set of items, SUS minimizes respondent burden, ensuring quick and straightforward assessments. The questionnaire's versatility allows it to be applied to various robotic interfaces and applications, making it adaptable to the diverse functionalities of robotic systems.[82] Additionally, the SUS's scoring system provides a quantitative measure of usability, aiding in the comparison of different robots. As a well-established and validated tool, SUS has gained credibility in the field, offering a reliable means for designers and researchers to gather valuable feedback, identify usability issues, and make informed decisions to optimize the user experience with robotic technologies.

The UEQ, with its simplicity and comprehensiveness, provides a holistic assessment of user experience by measuring key dimensions like attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty.[9] It offers a standardized approach that allows for reliable comparisons across different interfaces or products. Fitriana et al.,[83] believed that the comprehensive nature of UEQ allows for the assessment of diverse aspects such as attractiveness, efficiency, novelty, and dependability, providing a holistic perspective on the user's interaction with a product or system. Hussain et al.,[84] also mention that the standardized format of UEQ facilitates consistent evaluations across various contexts, contributing to reliable and comparable results. With its user-friendly design, UEQ ensures accessibility for a wide range of respondents, thereby promoting high response rates and yielding valuable insights. Additionally, the questionnaire's flexibility allows it to be adapted to different interfaces and applications, enhancing its applicability across diverse domains. UEQ's ability to generate actionable feedback makes it a valuable tool for designers and researchers, enabling informed decision-making to optimize and enhance user experiences. Moreover, the flexibility of the questionnaire enables adaptation to various interfaces and applications, thereby enhancing its relevance across diverse domains for robotic systems. The UEQ's capacity to generate actionable feedback establishes it as a valuable tool for robotic designers and researchers, facilitating informed decision-making to optimize and enhance user interactions with robotic technologies.[85]

On the other hand, QUEST focuses on specific aspects such as user satisfaction, efficiency, and engagement, providing valuable insights into the usability and user interaction of a system.[86] These questionnaires offer a standardized and reliable approach for assessing the usability aspects specific to health systems, making them essential tools in this field of research. This evaluation tool is specifically tailored for assistive technology, making it uniquely suited for appraising robots designed to aid individuals. QUEST's structured format and focus on user satisfaction allow for a comprehensive understanding of how well a robot fulfills its intended purpose. Its well-defined categories, such as effectiveness, ease of use, and satisfaction, facilitate a detailed analysis of user experiences.[48,54,56] Demers et al.,[87] believed that QUEST offers a standardized and validated framework, ensuring reliability and consistency in evaluations. The adaptability of QUEST to different assistive robotic systems contributes to its versatility in capturing varied user perspectives.[48,56] With its emphasis on user satisfaction and its established reliability, QUEST stands out as a valuable instrument for gaining insights into the performance and impact of assistive robots, aiding designers and researchers in refining and optimizing these technologies to better meet user needs. In conclusion, the adaptability of QUEST to diverse assistive robotic systems further enhances its versatility, capturing varied user perspectives. With a strong emphasis on user satisfaction and a proven track record of reliability, QUEST emerges as an indispensable tool for discerning the performance and impact of assistive robots. It serves as a guiding resource for designers and researchers, aiding in the continual refinement and optimization of these technologies to better address user needs in the ever-evolving landscape of health systems and assistive robotics.

In the end, it should be mentioned that by understanding the questionnaires commonly utilized in these domains, stakeholders involved in the development and evaluation of robots and smart wearables can benefit from a standardized approach. Consistency in usability assessment enables benchmarking, comparison of results, and identification of best practices. Moreover, the utilization of well-established questionnaires facilitates knowledge sharing and collaboration among researchers, leading to the advancement of usability evaluation methodologies.

### *Limitations of the study*

There were a few limitations in our study. Firstly, the inclusion criteria for this study only considered articles published in English, potentially excluding relevant studies published in other languages. Additionally, the search for related studies was conducted using three scientific databases: Scopus, PubMed, and Web of Science. To ensure more comprehensive results, it is recommended that future studies include articles published in other languages and a broader range of databases. Furthermore, it is important to note that this study did not conduct a critical appraisal of individual sources of evidence, and this limitation should be addressed in future studies.

## Conclusion

This paper has identified the most common and widely used questionnaires employed in the evaluation of the usability of robots and smart wearables. The SUS and Post-Study System Usability Questionnaire (PSSUQ) emerged as the predominant questionnaires utilized for assessing the usability of smart wearables. Furthermore, the SUS, UEQ, and Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST) were identified as the most commonly used questionnaires for evaluating the usability of robots.

The utilization of these questionnaires plays a crucial role in enhancing the design and user experience of robots and smart wearables. By incorporating these widely used evaluation tools, researchers and practitioners can gain valuable insights into the strengths, weaknesses, and areas for improvement. This knowledge can drive advancements in creating more user-friendly and efficient technologies within the dynamic realm of robotics and smart wearables. Continued exploration and application of these questionnaires will contribute to the ongoing evolution of these technologies, ultimately benefiting users and enhancing their overall satisfaction.

**Acknowledgments**: The authors thank the Central Library and Documentation Center of Kerman University of Medical Sciences for providing access to knowledge base references required for this study.

**Authors' contributions:** Khadijeh Moulaei contributed to the conceptualization; data curation; formal analysis; investigation; methodology; project administration; writing—original draft; and writing—review and editing. Reza Moulaei contributed to the conceptualization; data curation; formal analysis; investigation; methodology; resources; Kambiz Bahaadinbeigy contributed to the investigation; writing—review and editing.

**Availability of data and material:** All data relevant to the study are included in the article.

**Declaration of conflicting interests:** The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

**Funding:** The authors received no financial support for the research, authorship, and/or publication of this article.

**Guarantor:** KHM, KB.

**Supplemental material:** Supplemental material for this article is available online.

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