Co-design the Acceptability of Wearables in the Healthcare Field

Paolo Perego(✉), Martina Scagnoli, and Roberto Sironi

Design Department, Politecnico di Milano, Milan, Italy
{paolo.perego,martina.scagnoli,roberto.sironi}@polimi.it

Abstract. Nowadays, health is perceived as autonomy, both in the management and assessment of care processes. With Wearable Technology, tech companies and national health services move healthcare in everyday life to a better life. Wearables are already functionally high performing, but they still have acceptability and usability issues, especially in digital immigrants. Mobile health could contribute to patient empowerment in the digital health revolution if the human feels fulfilled by the new experience proposed.

This paper presents a case study of co-design and co-evaluation applied to a wearable service system for monitoring and driving self-rehabilitation at home. The participatory approach has been used to investigate the complex relationship between technical and human factors. Rapid Prototyping allows for developing tangible tools as testing and communication one. The different users and stakeholders involved in the project used the prototypes as tangible interfaces to understand and share their needs. The goal of this iterative process of interaction and reflection is to design a quality user experience.

This paper aims to show how design-driven methods and tools can effectively conduct Research-through-Design to increase the acceptability of wearable systems. The positive results of the usability tests during the Multimodal Wearable case study show that wearable systems' acceptability depends on the perceived user-friendliness, which is strictly connected to the co-design process.

Keywords: Wearable · HCI · Research-through-Design (RtD) · Co-design

1 Introduction

Developments in Information Technology (IT) led to an improvement in people's quality of life. The Internet of Things (IoT) remodels the Healthcare system, making it ubiquitous and increasingly a home centered [1] and person-centered care. It has been recognized that the domestic context, with its familiar atmosphere [2], offers a better and faster healing experience and quality of care. It has been demonstrated, especially during the global COVID 19 pandemic when

S. Spinsante et al. (Eds.): HealthyIoT 2021, LNICST 432, pp. 21–32, 2022.
https://doi.org/10.1007/978-3-030-99197-5_2

people have learned to reset much of their lives within their home and proximity spaces, that connected digital devices are a potential medium to interact with the outside world. Personal Health Systems (PHSs) are playing an essential role in providing an at-home system of cure, monitoring, prevention, and a personalised care, since are developed and tailored with the patient for better treatment [3,4].

In the last years, electronic and mechanical miniaturization brought compact computing devices into clothing and other accessories that can be worn comfortably on the body [5]. A wearable device is usually an intelligent object which can include sensors, actuators, smart fabrics, power supplies, Wireless Communication Networks (WCNs), processing units, and multimedia devices [6]. Wearables can be used in various end-user lifestyle sectors, offering the same possibility to receive continuous personal monitoring and access information anytime and anywhere [7].

In the medical sector, Smart Wearable Devices (SWDs) have been diffused from the late 1990s as Wearable Health Devices (WHDs) to help in "patient empowerment" [8]. Smart wearable technologies, with sensory and scanning features such as biofeedback and tracking of physiological function, enable remote monitoring healthcare services to help manage patients' health and well-being [6]. Although wearables are mature from a technological point of view, it has been noted that the adoption and diffusion of these in medical eld are relatively low [7]. Most wearables have a short life cycle, and user acceptance in medicine is still not as widespread as expected [9]. As part of PHS technologies, despite the advantages they offer to various health and social care systems [4], they seem to have not yet had a rapid spread.

Wearables are not yet fully accepted because often understanding how they work is not easy, the way they are used does not feel natural, and therefore the potential that wearables have to offer is not even understood. For example, research on adopting SWDs to assist healthcare in China examined the potential factors affecting user adoption. The study found that the influence of trust on users' attitudes towards SWDs was the most significant, which is followed by compatibility, perceived usefulness (PU), and perceived ease of use (PEOU) [6].

How to solve the problems of acceptability and usability of wearables? By considering human needs and competences that are strongly linked to the type of users (digital natives or digital migrants) within the design and development methodology. Human Centered Design (HCD) tools help to analyze the real contexts of use for which to design, and participatory design tools help to co-design with the real users of those same contexts, including them for all intents and purposes in the design team made up of all project stakeholders. Since wearables are service hubs that can act as active or passive interfaces [10], it is essential to have a broader system view and focus on the design of relations and interactions complexity about technology-to-person services. This challenge requires a multi-stakeholder process of Product Service System (PSS) design [4] conducted with a design-driven approach. This paper shows the development method used during a co-design and co-evaluation case study for remotely monitored rehabilitation wearable service systems. The method has implemented a participatory approach with various stakeholders and users to improve usability and acceptability, investigating and testing the relationships between technical and human factors in developing the wearable system.

2 Reflecting on the Contribution of Design to Enhance the Wearables' Acceptability

The IoT has enabled digital PSSs to capture and exchange data, creating a network of ubiquitously connected devices within our physical and social spaces. Nowadays, technology permeates most aspects of everyone's life: smartphones have become the most indispensable personal mobile tool to interact with, allowing to act passively and actively on the world. Wearables then are more complex devices and require hybrid designs. They come from the synergy between multiple science domains - such as biomedical technologies, micro, and nanotechnologies, materials engineering, electronic engineering, and information and communication technologies [12].

HCD methodologies and holistic design requirements identification tools, help build an overview of technical and human factors [13], from different stakeholder perspectives, which can be used as a canvas to visualize and draw potential relationships to be implemented in the project. This article aims to show the contribution of the phenomenological design approach to improve the acceptability of wearables. In particular, we consider the double diamond model to describe the process of acquiring and defining design requirements, focusing on its valid iterative progression and the possibility of creating several research/analysis/test/evaluation loops simultaneously. Designing acceptability means focusing on UX design by analyzing user attitudes and intentions in adopting the proposed new information system from time to time [6]. Early acceptability design concept translates into the involvement of the different users and stakeholders, from the earliest stages of the production process. Since the user acceptance of wearables depends on transversal socio-technical relations, and the final usability and satisfaction depend on a combined focus on technical and human challenges, a co-design approach enhances the coexistence of different considerations in the design projects. It encourages dialogue between various experts (including final users). As is the case in Human-Computer Interaction (HCI) studies, it might be helpful to consider each requirement as a combination of both factors (technical and human) and categorize it according to physical, cognitive, and emotional ergonomics [9]. Additionally, verification and validation are necessary to define them according to their specific evaluation technique and the degree of development at which the process is [9]. Prototyping is a promising tool to support the different definition phases of the digital PSS development, the co-design process, and knowledge sharing techniques about intangible elements by fostering an iterative and interactive process of co-evaluation [11].

2.1 An Empirical Case Study to Design an Acceptable Wearable PSS

This paper focuses on testing the above-mentioned theoretical concepts, executing, and analyzing a design project for the healthcare sector.

The project, called Multimodal Wearable (MW), was funded by "Centro Protesi" INAIL, one of the research centers of the National Institute for Insurance against Accidents at Work. It aimed to design a wearable system for monitoring and evaluating motor rehabilitation activities in post-stroke patients, offering a more personal and personalized at-home service to conduct Rehabilitation in autonomy. All this conveys the benefits of extending care in the home environment to improve the quality of the rehabilitation experience during the recovery period, accelerate the healing process of the injured worker, and speed up his or her reintegration into work [15]. For the different contexts that the project would touch, designing with a horizontal and holistic vision was mandatory to make it arise from their intersection. Increasing the performance expected from the new system led to adding some degrees of complexity, causing a potential decrease in usability.

The Octopus methodology [14] was used as the primary reference to organize the different human-centered design principles provided by ISO 9241 and the different collaborative design-evaluation and review phases the MW project and its stakeholders provided. The iterative nature of the Octopus methodology has helped the project better define itself in its complexity, expanding the methodology [15] toward the design of the User Experience (UX) and the User Interaction (UI) of the Internet of the body.

To design for the new scenario of use resulting from the intersection of the rehabilitation and domestic contexts and the human body as a surface for wearables, the following were explored in-depth:

– User Experience and the network of interactions between users and the wearables' system.
– Wearability and human factors.

Approaching human performance from a data perspective could mean relying on quantitative, objectively valid sources to focus on the design of qualitatively more appropriate and effective communication. The new technology and interactive experience emerged from the systematization of information from desk and shared context analyses. Interviews, focus groups, and participatory design actions have supported the design team and the MW project stakeholders to conduct the User Research in the real context.

In the rehabilitation center, chosen as a reference environment, two focus groups were led, and ad-hoc questionnaires were administrated to 30 participants [15].

Through the questionnaire, during the first focus group, the design team wanted to investigate the response of patients and technologists on different issues such as preferences in the detection of wearable system parameters, wearability, morphology and modularity of the wearable system, aspects related to the interface and user/system interaction and engagement levels, elements about usability and aesthetic acceptability. There were two types of users: the patient, as a wearer, and primary/direct user of the wearable or also called Actor User (AU), and the technologist as a secondary user and part of the Professional Users (PU), who can process the collected data and indirectly guide and monitor the patient parameters [14]. Both patients and technologists are interested in monitoring biomechanical data and those more related to movement. For both, the wearable system needs to motivate and follow the patient in the rehabilitation path through a dedicated interface (APP or other). Consequently, patients prefer to interface with the wearable system through the smartphone. The PUs supports the importance of having real-time data to monitor and evaluate the rehabilitation activity or having data available at the end of the session. Patients would like to send the data immediately after the training is completed. In general, according to the patient's pathology, they agree to opt for a wearable system divided by body districts, who prefer to receive a complete configured system from the PUs. For PUs, the comfort aspect of the wearable is an essential aspect to consider, compared to AUs, who assume that wearing time aspects are more relevant. The workshop has been used to have either an aesthetically discreet and almost invisible system concept or a customizable one to manage the aesthetic level independently.

Through these participatory design tools, it is shown how users were considered active members from the beginning of the MW project. Therefore, the different stakeholders involved in the co-design team were:

- Patients with different pathologies from the rehabilitation center.
- Physicians, technologists, and healthcare workers from the rehabilitation center.
- Technologists from INAIL.
- Technologists and Designers from the design team.

This first co-design session highlighted human and technical factors from different user perspectives. The first level of contextual factors defined the choice of technologies to be implemented and the preferred modes of interaction. The technological study then took three parallel development paths towards the setting of:

- A Wearable system.
- A smart garment.
- An APP for smartphone.

The APP has the double task as Data visualization and Data Processing Point (DPP) [14]. The second focus group has been administered with patients and therapists to deepen the requirements related to preferences about usability, Graphical User Interface (GUI), wearable aesthetic, time and space of use. The patients involved in the focus groups and survey were working-age people following a hospitalized rehabilitation path due to myoplasia or post-stroke. Thanks to this double patient type, focus groups have the further objective of assessing

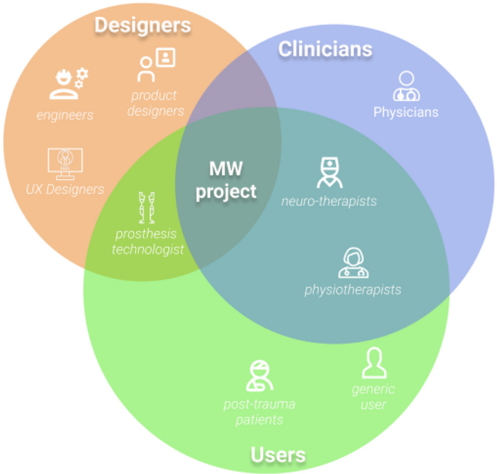

Fig. 1. Representation of MW Project's stakeholder.

how the same aspects were received and characterized according to the type of pathology. Another mandatory evaluation has been related to data visualization and storing. Through interviews, it has also been possible to understand which data to display, how, where, and how to store/process/send them. In general, operators required a simple management system focused on physical and cognitive ergonomics. Patients need the simplicity of use, ease of wearing, cleanliness, breathability, and therefore parameters linked to the effectiveness and usability of the system, rather than aesthetics. The comment: "I would like it to look like an everyday object", was very explanatory. To complete identifying user-side requirements in the domestic context, a questionnaire has been administered to new users to be filled in online. In this questionnaire, the user had to reply about the relationship between their fitness status, physical activities practiced in the domestic context, and the possible presence of musculoskeletal pathologies where relevant. The participants had to assess some parameters based on the indices of time spent, posture taken, body district affected, and the level of perceived fatigue. In the final part, questions related to the user's work activity were also proposed to assess the user's attitude to use wearables for risk prevention at work. The results have shown that, for the interviewed, the most exciting aspects of being monitored are the feedback about postures during home and work activities and the stress related to these. This collaboration process during analysis, synthesis, sharing, and reflection with the project's various users and stakeholders led to a balancing of the design requirements according to physical, cognitive, and the users' experience (e.g., from direct use to the emotional aspects). Thanks to the iterative process, typical of user centered design approach, co-design could be led since the beginning of the design process.

2.2 Improve Wearable Acceptability Through UX and UI Design

After the first analysis with focus groups, interviews, and questionnaires, quantitative and qualitative data have been gathered to apply the so-called mixed method for collecting "what and why", related to acceptability and usability problems. Defining a good interaction with wearable devices means integrating data evaluated in the previous phase to design the most appropriate, intuitive, and uncomplicated experience for users. The content and representation of the information to be shared must be adequate to each mental profile that should receive it and to the context of reception [14]. How can the patient better understand and interact with all the wearable system components and proactively improve his/her healthcare service? How to create a transparent system architecture and design simple patient actions?

The Multimodal Wearable project has been chosen to resolve system complexity by designing a smart garment with fixed wearable marks. This led to the definition of a modular multi-parameter wearable system, available in upper, lower, or upper/lower versions. The positions of the inertial modules for sensing biomechanical data and the module for monitoring physiological data depended on the body districts to be monitored. The decision to create garments with the wearable system receptacles already in place was driven by the desire to help users by providing them with a near-complete solution that was easy to wear and use autonomously, by placing the right wearables in the proper receptacle. The positioning of wearable has been designed focusing on the guidance of affordance. For Norman, affordance is an object's design aspect that suggests how the object should be used, a visual clue to its function and use. Affordance refers to the perceived and actual properties of the thing [16]. The existence of an affordance depends upon the properties of both the product and the user's perception. The design team mapped out areas of the body where wearables would be less invasive and, at the same time, more effective for sensing biomechanical body movements and physiological parameters. Design for wearability and comfort also consider aesthetic and social acceptability values in the definition of proper body areas [17]. Creating shapes that recall everyday objects helps people contact technology and increase acceptability and usability. For this reason, the device has a shape inspired by polished stones used for relaxing massages. Simple experience indicates that compact short shapes, like those of stones or control knobs, invite to be contacted by a fingertip grip [16]. Moreover, to ensure the uniqueness of positioning and coupling between the wearable and the receptacle positioned on the smart garment, and not to generate frustration during the wearability phase, were considered:

- Positioning strategy.
- Shape orientation.
- Docking system to the garment.
  - to co-reflect with other project users and stakeholders and improve from a usability perspective.
  - fixing system
- Charging case.

To address the correct wearable positioning on the smart garment, the strategy of making same-colored markers for each device/position pair was adopted. Considerations about wearable shape orientation on the on the garment, conduct the design team to pursue two roads at the same time:

- The definition of an asymmetrical top/bottom shape (to ensure the correct electrical contact).
- Same outline for wearable and receptacle to maximize contact stiffness.

A magnetic coupling/contact type capable of ensuring mechanical and electrical tightness and comfort during the coupling process was developed from a technological perspective. While implementing different design requirements, the design team first used various CAD/CAE tools and inspirational mock-ups to co-design affordance. Therefore, rapid prototyping has allowed to materialize them to test their effectiveness with the final user in a real-life context.

Using a range of production techniques and technologies, both additive and traditional, it was possible to harmoniously combine hard and soft parts in the same object to maximize wearability and comfort. It was possible to use different 3D printing materials to obtain simple conceptual models and functional multi-material prototypes to study and understand the interaction. At the same time, the relationship between the size of the wearable device (depending mainly on the implemented technology and battery) and its position on the body was achieved concerning human factors considerations. The communication and networking part of the system, also related to user-product interaction, was iteratively designed, prototyped, and co-evaluated through users' tests. MW wearables showed system state and error by a multi-color LED included in the input button [15]; this aspect about error and feedback has also been discussed with users who prefer, as Norman indicates [18], to be aware of the system's status. From this point of view, Smartphone APP was another important part of the feedback. The APP has been thought not only to display collected data but also to help the user during system configuration, let him aware of it in case of error, device problem, or battery consumption. Users participated in making the GUI design more understandable by testing its application of Nielsen's heuristics [18]. Real tests were possible since the same smartphone could connect to multiple devices via Bluetooth. Users could test the proposed MW experience with an actual high-fidelity prototype shown in Fig. 1.

The last co-design session was mainly in a Rehabilitation center (Ospedale Riabilitativo Valduce Villa Beretta" di Costa Masnaga). A panel of ten healthy subjects tested four complete MW systems (smart garment, wearables, and APP). Test on subjects with pathologies was not conducted for safety reasons due to the actual Covid 19 pandemic; they evaluated the system without wearing it. The high-fidelity MW prototypes were assessed according to the parameters of:

- The kinematic accuracy of the biomechanical model of the shoulder district, according to a validation protocol developed by the Rehabilitation center.
- The usability test (evaluation of ergonomics and aesthetic acceptability) using an ad hoc developed SUS (System Usability Scale) questionnaire (Fig. 2).

Fig. 2. Prototypes of the hard components and the GUI of the MW system.

Healthy subjects and therapists performed wearability tests and biometric surveys. Subsequently, they were administered to a standardized questionnaire (SUS - System Usability Scale) [19]. and other questions based on the Likert scale to measure the degree of acceptability of the system. The results of this evaluation showed an excellent adherence between the high initial expectations of the subjects involved and the post-test evaluation of the system. This means that the system has responded to the expected needs of the users.

In general, the perceived quality of the system was high, and this value was substantially confirmed by the totality of the parameters analyzed in the usability assessment. It should be emphasized that the system's quality of the information received, the overall acceptance, and the appropriateness of the operations carried out by MW reached an optimal score (¿6/7). At the same time, the other evaluation parameters were at very good values, close to the optimal; slightly lower the scores related to wearability (4.1/5) and aesthetic acceptability (5.40/7). In particular, the values of these two parameters underline the opportunity to improve the system by intervening on suit aesthetics and dressing and undressing method. The usability test also measured the wearing times of the system, which was around 4 min for dressing and around 1 min and 30 s for undressing, which are acceptable values when compared with normal clothes dressing. Results showed excellent adherence between the high initial expectations of the project's stakeholders and the post-test evaluation of the MW system. The quality of the information received by the system, the overall acceptance, and the appropriateness of the operations carried out by MW achieved an optimum score. At the same time, the other evaluation parameters have been significant. Wearability and aesthetic acceptability have been rated good. Users asked for improvements to the opening system in the smart garment (to facilitate especially wearability by patients with hemiparesis) and increase sizing. The system application obtained, in general, a good evaluation, SUS score 75.5/100, which becomes optimal when looking at the therapists' data 87.5/100. This demonstrates the effectiveness of the new methodologies adopted [15].

On the other hand, from a technological point of view, the MW system has been validated by having it worn by six subjects to perform the function test compared with other motion tracking and optoelectronic technology systems. The selected sample represents a sufficiently large sample of users and stakeholders to understand and highlight the most critical issues related to the usability of PSSs [20,21] due to the criticality of the Covid-19 breakout, the sample of users was not expanded.

3 Conclusion

In order to be adopted by the healthcare system, in a pervasive healthcare perspective, and to be recognized and accepted by end-users as understandable and practical, wearable should be developed with the user at the center of the design process, and by taking co-design approach as the right one to deal with users' needs, acceptance and usability. This increases the completeness of the result expected by those who will be the final users of the project, having started from their needs. It is a matter of defining the starting point well, analyzing it from both human and technical points of view, to create a solution as close as possible to the needs discovered at that point. Adopting human-centered tools help to explore a technological-driven field like Wearable Technology with a design-driven approach, giving more importance to aspects related to the human side of the experience. Maintaining users at the center facilitates the objectives and constraints identification and the design gap definition. Then, discussions between the various stakeholders help to co-evaluate and co-reflect on the multiple outcomes of the prototyping process that functioned as rapid cycles of collaborative learning. Moreover, prototypes played a central role in the process of thinking about how design could influence the improved acceptability of wearables since they allowed:

- To support each design team component to reflect on its ideas.
- To share ideas within the design team.
- To co-reflect on the prototyping process and progress it.
- To test the solutions created in the real context and co-reflect with other project users and stakeholders.

In this way, it is possible to simultaneously assess body-centered issues, material selection, technology, product-user communication, physical ergonomics, and comfort issues from both performance and usability points of view. This approach has been tested during the development of the Multimodal Wearable system for motor rehabilitation, obtaining good results in terms of design outcome for users' expectations and needs. The test analysis has shown that the system has good approval ratings from most of the rehabilitation process actors: users, caregivers, and clinicians.

Acknowledgments. This work has been supported by "Centro Protesi INAIL" - Vigorso di Budrio (BO), Italy, the main research center of the National Institute for

Insurance against Accidents at Work. The authors would also like to thank all the focus group participants for their willingness and patience, and to eng. Angelo Davalli, eng Emanuele Gruppioni and eng. Rinaldo Sacchetti of INAIL Centro Protesi for supervising the research.

References

1. Rahmani, A.M., et al.: Smart e-Health gateway: bringing intelligence to Internet-of-Things based ubiquitous healthcare systems. In: 12th Annual IEEE Consumer Communications and Networking Conference. CCNC 2015, pp. 826–834 (2015)
2. Lupton, D.: The digitally engaged patient: self-monitoring and self-care in the digital health era. Soc. Theory Heal. **11**(3), 256–270 (2013)
3. Flores, M., Glusman, G., Brogaard, K., Price, N.D., Hood, L.: P4 medicine: how systems medicine will transform the healthcare sector and society. Per. Med. **10**(6), 565–576 (2013)
4. Schartinger, D., et al.: Technology Innovation Management Review Personal Health Systems Technologies: Critical Issues in Service Innovation and Diffusion (2015)
5. Wright, R., Keith, L.: Wearable technology: if the tech fits, wear it. J. Electron. Resour. Med. Libr. **11**(4), 204–216 (2014)
6. Gao, S., Zhang, X., Peng, S.: Understanding the adoption of smart wearable devices to assist healthcare in China. In: Social Media: The Good, the Bad, and the Ugly, pp. 280–291 (2016)
7. Niknejad, N., Ismail, W.B., Mardani, A., Liao, H., Ghani, H.: A comprehensive overview of smart wearables: the state of the art literature, recent advances, and future challenges. Eng. Appl. Artif. Intell. **90**, 103529 (2020)
8. Dias, D., Cunha, J.P.S.: Wearable health devices-vital sign monitoring, systems and technologies. Sensors (Switzerland) **18**(8) (2018). (MDPI AG)
9. Francés-Morcillo, L., Morer-Camo, P., Rodríguez-Ferradas, M.I., Cazón-Martín, A.: Wearable design requirements identification and evaluation. Sensors (Switzerland) **20**(9) (2020)
10. Francés-Morcillo, L., Morer-Camo, P., Rodríguez-Ferradas, M.I., Cazón-Martín, A.: The role of user-centred design in smart wearable systems design process. Proc. Int. Des. Conf. Des. **5**(1), 2197–2208 (2018)
11. Kleinsmann, M., Ten Bhömer, M.: The (New) roles of prototypes during the co-development of digital product service systems. Int. J. Des. **14**(1), 65–79 (2020)
12. Dias, D., Cunha, J.P.S.: Wearable health devices-vital sign monitoring, systems and technologies. Sensors (Switzerland) **18**(8) (2018)
13. Morcillo, L.F., Morer-Camo, P., Ferradas, M.I.R., Martín, A.C.: The wearable co-design domino: a user-centered methodology to co-design and co-evaluate wearables. Sensors (Switzerland) **20**(10) (2020)
14. Marin, J., Blanco, T., Marin, J.J.: Octopus: a design methodology for motion capture wearables. Sensors (Switzerland) **17**(8), 1–24 (2017)
15. Perego, P., Sironi, R., Scagnoli, M., Fusca, M., Gruppioni, E., Davalli, A.: Multimodal Wearable System for Motor Rehabilitation - Design Perspective and Development, pp. 99–106 (2021)
16. Wolf, A., Krüger, D., Miehling, J., Wartzack, S.: Approaching an ergonomic future: an affordance-based interaction concept for digital human models. Procedia CIRP **84**, 520–525 (2019)
17. Zeagler, C., Gandy, M., Baker, P.: The assistive wearable: inclusive by design. Assist. Technol. Outcomes Benefits (ATOB) **12** (2018)

18. Nielsen, J.: Ten usability heuristics (2005)
19. Kortum, P.T., Bangor, A.: Usability ratings for everyday products measured with the system usability scale. Int. J. Hum. Comput. Interact. **29**(2), 67–76 (2013)
20. Lewis, J.R.: Sample sizes for usability studies: additional considerations. Hum. Factors **36**, 368–378 (1994)
21. Nielsen, J., Landauer, T.K.: A mathematical model of the finding of usability problems. In: Proceedings of the INTERACT'93 and CHI'93 Conference on Human Factors in Computing Systems, pp. 206–213 (1993)