**Technology requirements for vestibular rehabilitation: Implications for human-computer interaction and human-robotic interaction**

**Abstract**

**Background:** Vestibular rehabilitation (VR) isthe most effective treatment method for the symptoms of dizziness, vertigo, imbalance, and nausea caused by vestibular disorders, but adherence levels are low. A main challenge in VR is that it calls for many short exercise sets during the day, which can worsen symptoms and impair balance in the short term. Technological tools have the potential to increase adherence, but to date, there has been no comprehensive analysis of the specific needs from technology, its limitations, and concerns regarding its use in the context of vestibular rehabilitation.

**Objective:** The aim of the study is to identify the main features required from technology for vestibular rehabilitation, as perceived by patients with vestibular disorders and vestibular physical therapists, using a socially assistive robot as a test case.

**Methods:** We conducted a qualitative study with six focus groups (N=39). Three groups of patients (N=18), and three groups of physical therapists (N=21) participated in this study. Each focus group included structured questions on technologies for vestibular rehabilitation, a presentation of two videos with a socially assistive robot (SAR), and an online survey. Thematic analysis with a mixed deductive and inductive approach was used to analyze the data

**Results:** Participants preferred phone applications or virtual/augmented reality platforms over an embodied robotic platform. The technology should be adaptive to XX, gamified, easy to use, safe, reliable, portable, and accessible remotely by the therapist. The technology should provide feedback on the quality and quantity of exercise performance and monitor these factors while considering the tolerability of the ensuing disruptive symptoms. Participants expected that using technology as part of the rehabilitation process would shorten exercise sessions and improve clinical outcomes compared to standard care. Socially assistive robots for vestibular rehabilitation were perceived as useful mostly for children and patients with chronic vestibular disorders, and their potential use for rehabilitation raised concerns regarding safety, ethics and technical complexity.

**Conclusions:** This study provides a practical framework for the development and the design of vestibular rehabilitation technologies that utilize human-computer interaction (HCI) or human-robot interaction (HRI).

Key words: Vestibular Rehabilitation; Technology; Human Computer Interaction (HCI); Human Robot Interaction (HRI); Socially Assistive Robots (SARs).

**1. Introduction**

Vestibular disorders cause a wide range of symptoms, including dizziness, vertigo, imbalance, and nausea (McDonnell & Hillier, 2015; Strupp et al., 2019), leading to a decrease in quality of life for many (Enloe & Shields, 1997). Approximately eight percent of the population suffers from vestibular problems during their lifetime (Neuhauser et al., 2005a), and almost 70% of the people with vestibular disorder reported they had to reduce their workload as a result of the symptoms they experienced (Kovacs et al., 2019).

Vestibular rehabilitation is an effective treatment for vestibular disorders (Hall et al., 2022a; Herdman et al., 2015; McDonnell & Hillier, 2015). According to the latest guidelines of the American Physical Therapy Association (APTA), patients who suffer from vestibular hypofunction should be treated with Vestibular rehabilitation (Hall et al., 2022a). Vestibular rehabilitation should include gaze-stabilization exercises, balance exercises, and habituation exercises. These exercises involve repetitive head movements, performed several times per day for a short period of time, for 4-6 weeks. These exercises are provocative and stimulate dizziness, unsteadiness and nausea for short periods of time. Some exercises include fast head movements while standing or walking, which can challenge one's balance (Hall et al., 2022a). Although vestibular rehabilitation is effective, it meets with low levels of adherence and accessibility issues, which need to be addressed in order to improve treatment outcomes (Cohen, 2011; Meldrum et al., 2020, Kalderon et al., Unpublished data). Low adherence is indeed common in a wide range of rehabilitation fields that require self-practice (Bohplian & Bronas, 2022; Essery et al., 2017; Jack et al., 2010; Zhang et al., 2022).

A variety of technologies have been used to enhance the rehabilitation experience, which may result in improved adherence to treatment. One study examined the use of socially assistive robots in rehabilitating upper limbs following a stroke (Feingold-Polak et al. ,2021). The authors report that there were no drop outs from the group that completed the rehabilitation exercises with a robot, as opposed to the two control groups; the former group also achieved better improvement in clinical outcomes (Feingold Polak, unpublished data). Another example is the use of phone applications, according to a study by Backer et al., (2022) (Backer et al. ,2022). A phone application for rehabilitation after total hip and knee arthroplasty benefited patients and helped reduce their levels of pain, especially in the short term (Backer et al., 2022????). Virtual reality is another technology that has been extensively researched in rehabilitation. Chen et al. (2022) have shown that virtual reality is effective in cardiac rehabilitation, and helped increase exercise capacity and mental function. Moreover, following the COVID-19 pandemic, there has been an increase in the use of telerehabilitation platforms in various fields of rehabilitation, such as cardio-pulmonary rehabilitation, neurological rehabilitation and pediatric rehabilitation (Ahmadi Marzaleh et al., 2022; Kaur et al., 2022; Mishra et al., 2022). Kaur et al., (2022), for example, showed that telerehabilitation has several advantages, including working in the patient's natural environment, reducing costs, and facilitating access to care.

Researchers have also examined the use of different technologies to optimize and increase adherence in vestibular rehabilitation. The use of virtual reality has been studied in several studies, and it has been shown to be beneficial mainly for individuals with peripheral vestibular dysfunction and also showed improvement in the Dizziness Handicap Inventory compared with traditional vestibular rehabilitation (Chu et al., 2022; Hsu et al., 2017; Rosiak et al., 2018; Xie et al., 2021). Nevertheless, virtual reality is not commonly used in vestibular rehabilitation practice, perhaps due to the high cost of the equipment (Rosiak et al., 2018), a motion sickness sensation related to prolonged exposure to digital screens (cybersickness) (Saredakis et al., 2020) or the need to practice several times a day. The use of a phone application is another technology for vestibular rehabilitation (DSilva et al., 2022; Nehrujee et al., 2019). Early evidence suggests that phone applications can be useful in vestibular rehabilitation and make the process more enjoyable (DSilva et al., 2022; Nehrujee et al., 2019). However, their feasibility and their effect on treatment outcomes have not yet been established among patients with vestibular disorders (DSilva et al., 2022; Nehrujee et al., 2019).

An effective way to develop new technology is through the use of participatory design. Participatory design involves target populations in the technology development process by providing their opinions and feedback, resulting in a technology that meets stakeholder needs (Fischer et al., 2020; Rogers et al., 2022; Schuler & Namioka, 1993; Spinuzzi, 2005). Feingold Polak & Levy-Tzedek discussed the importance of adapting rehabilitation technology to various preferences and impairment levels to get better outcomes and encourage users to use it for a long period of time (Feingold Polak & Levy-Tzedek, 2021). An acceptable method to achieve these benefits and to develop appropriate technology is to conduct focus groups (Bar-On et al., 2022a; Dembovski et al., 2022a; Gill et al., 2008; Polak et al., 2019). In focus groups, a group interview is held in order to collect information (Gill et al., 2008; Halliday et al., 2021; Morgan, 1997), and to allow participants to interact with each other. By doing so, a broad understanding of the topic can be gained (Crossley, 2002; van Teijlingen & Pitchforth, 2006).

To the best of our knowledge, there has not yet been a study that examined the technological needs of clinicians and patients in the field of vestibular rehabilitation. In light of previous studies that involved a variety of stakeholders in developing rehabilitation technologies (Bar-On et al., 2022a; Dembovski et al., 2022a; Koren et al., 2022; Polak et al., 2019), we believe that conducting focus groups with both clinicians and patients will enable to gain a broader understanding of the difficulties, desires, and concerns regarding the development of technology for vestibular rehabilitation.

The aim of the study is thus to identify the main features required from technology for vestibular rehabilitation, as perceived by patients with vestibular disorders and vestibular physical therapists, using a socially assistive robot as a test case for such a potential technology. Our article presents the insights gained from focus groups in which the relevant stakeholders were asked about technology needs in general, and robotics in particular.

**2. Methods**

A qualitative research methodology with focus groups, based on a mix of inductive and deductive approaches to thematic analysis (Azungah, 2018). It was conducted in compliance with the Consolidated Criteria for Reporting Qualitative Data (COREQ)(Tong et al., 2007). We received approval for this study from the Ethics Review Boards at Ben-Gurion University of the Negev, and at Sheba Medical Center.

2.1. Participants

Two groups of stakeholders were of particular interest to us: patients suffering from vestibular disorders, and their primary therapists involved in the rehabilitation process, namely, vestibular physical therapists. We recruited patients from the Otolaryngology clinics of Sheba Medical Center and via emails that were sent to physical therapists. Physical therapists were invited directly or recruited through social media (Facebook). The recruitment process continued until data saturation was achieved (Hennink et al., 2019).

Patients were eligible if they had a vestibular disorder and previously or currently undergone vestibular rehabilitation. Patients were excluded if they had medical conditions or cognitive impairments that prevented them from engaging in vestibular rehabilitation. Physical therapists who had a certification in vestibular rehabilitation post-graduate course and had previous experience in vestibular rehabilitation were included. By using a purposive sampling method, a diverse group of individuals was selected based on their diagnoses (central, peripheral and functional vestibular disorders) and working settings (clinics, day care centers, and hospitals).

In total, six focus groups were conducted - three per stakeholder group. Each participant took part in one session; and each session included five to eight participants. We had a total of 39 participants: 18 patients and 21 clinicians. Taking into account the estimated no-show rate of 10-25%(Guest et al., 2017), the sample size was determined on the basis of similar studies with focus groups(Bar-On et al., 2022b; Dembovski et al., 2022b; Feingold Polak & Tzedek, 2020; Fruchter et al., 2022). There were 44 participants approached, of whom two patients refused to participate, and three patients canceled their attendance shortly before the meetings.

2.2. Research team

The facilitator of the focus groups (author LK) was a 34 years-old male, a licensed physical therapist with a master's degree in physical therapy, and a Ph.D. student in health sciences. At the time the focus groups were held (February 2022 – July 2022) he had seven years of experience as a physical therapist specialized in vestibular rehabilitation. Neither the facilitator nor the patients were familiar with each other prior to the study; some of the clinicians who were recruited to this study were colleagues of author LK. In each session, one member of the research team was present in order to provide technical assistance and to serve as an observer; the assisting team member took field notes without interfering with the discussions. The research team had previous experience with socially assistive robots and other technologies for rehabilitation and assumed that developing a tailored technology could potentially improve vestibular rehabilitation outcomes.

2.3. Procedure

We conducted six 60-90 minutes Zoom video conferencing sessions, which were recorded and later transcribed. At the start of each meeting, the group facilitator welcomed the participants and explained the objectives of the study. Each session included a structured verbal discussion (questions were also presented on the shared screen window), presentations of two videos, and an online Google form questionnaire, to which participants responded anonymously via a link sent to them in the following order:

**Q1:** *"In which ways do you think technology can help overcome barriers/limitations of adherence to vestibular rehabilitation exercises? “*

Following the first question, an example of robotic technology was shown to the participants in **Video 1** (see Supplementary Materials). This video was pre-recorded, and was meant to show an example of a Socially Assistive Robot (SAR) in context of vestibular rehabilitation. It included three theoretical scenarios: (a) the SAR invites a patient to do the exercise together; (b) vestibular rehabilitation exercises are guided by the SAR; (c) positive and negative feedbacks are provided on the performance of the exercise by the SAR.

**Q2:** *" Do you think you can benefit from the SAR shown in the video? how? "*

Following the second question we sent a link to the Google form question:*" On a scale of 0-100, to what extent do you think you would like to use the SAR? (0- not at all, 100- very much)"*

**Q3:** *" Do you think an interaction with an assistive robot can encourage you to do more vestibular exercises at home? Why, or why not?*

**Q4:** *" Would you use the SAR? Why, or why not? "*

**Q5:** *" Do you have any concerns regarding the use of the SAR? What are they? "*

To answer the last question, a second video was shown to participants with a variety of different capabilities and configurations of the SAR (e.g., animal-like vs. human-like figures, walking abilities, climbing abilities, moving on wheels). The next step was to determine what the preferences of the participants were, and if they had any other ideas for their ideal SAR.

**Q6:** *" If you could design a social robot to help you perform your vestibular exercises, what would it do? "*

These were preceded with more general questions related to vestibular rehabilitation, reported in (Kalderon et al., unpublished data).

We encouraged participants to express their views in an open manner. The facilitator approached some participants directly when he observed that they were quiet and asked for their opinions and suggestions.

2.4. Data analysis

Thematic analysis was used to analyze the transcribed text (Braun & Clarke, 2006; Rabiee, 2004). The transcribed text was coded separately by authors LK and AK. Once codes had been reviewed and agreed upon by the coders, they were sorted into categories. In collaboration with authors SL and YG, themes were then established. For each category and sub-category, the number of mentions is reported. We used Atlas.ti software, version 22, to analyze the qualitative data.

Quantitative data is presented using descriptive statistics. Ratio variables were tested for normality using the Shapiro-Wilk test. SPSS version 28 was used for the analysis of the quantitative data.

**3. Results**

**3.1 Participants**

We conducted six focus groups - three groups for each stakeholder, with 5-8 participants per group. Our study included 39 participants in total:

(1) Eighteen patients with 10 types of vestibular disorders (mean age: 49.7 ± 12.9 years; eight men and 10 women): Bilateral Vestibular Hypofunction (n=4), Vestibular Migraine (n=2), Vestibular Schwannoma (n=2), Persistent Postural Perceptual Dizziness (n=2), Cerebellar Ataxia with Neuropathy and Vestibular Areflexia Syndrome (n=2), Non-specific dizziness (n=2), Labyrinthine hemorrhage (n=1), Unilateral Vestibular Hypofunction (N=1), Mal de Debarquement Syndrome (N=1), Meniere's disease (N=1).

(2) Twenty-one vestibular physical therapists (mean age: 45.3 ± 8.7 years; Seven men and 14 women). The physical therapists had 18 years of experience (median) (range: 7-35 years). There were nine different types of clinical settings represented by the physical therapists - public outpatient clinics (n=13), private outpatient clinics (n=11), private home care (n=6), adult day care center (n=1), and hospitals: Pediatric rehabilitation (n=2), neurologic rehabilitation (n=1), geriatric rehabilitation (n=1), Ears, Nose and Throat department (n=1), and general hospital work (n=1).

**3.2 Assistive** **technology requirements for vestibular rehabilitation**

We identified four categories of requirements from technology (N represents the number of utterances). These requirements are summarized in **Figure 1**.

**3.2.1 Platforms and features to support exercise (N=30)**

Patients and physical therapists reported that the development of ***a phone application*** (N=18) is needed for vestibular rehabilitation, and that it could increase motivation to performs the exercises. Patients proposed several ideas of basic features that the phone application should include, such as the ability to monitor exercise performance, to provide feedback on performance and progression and to use reminders and customized time schedule to exercise. They also proposed more advanced features that could be helpful if integrated in the phone application, such as the ability to track eye movements and to share data with their sports tracking applications. From the physical therapists' perspective, one useful feature that the phone application should include is the ability to monitor exercise performance and to compare the data with other users, and to award prizes to users who practice more than others. They also suggested that using a cartoon character embedded in the phone application would be more practical than using physically embodied technologies, such as robots.

Another platform that was suggested by patients and physical therapists was ***virtual / augmented reality*** (N=6). Virtual reality was mentioned by patients, whereas physical therapists mentioned both virtual reality and augmented reality as potential platforms. Physical therapists suggested that if augmented reality platforms are developed, they should be used with light-weight glasses (as opposed to the currently available helmets). .

Patients and physical therapists said that the platform should be ***integrated with existing exercise accessories*** (N=5). One patient mentioned that the technology should be connected to a smart watch. Some physical therapists suggested it should work with existing computer software for gaze exercises, or with force plates that are able to asses postural stability. Others suggested that it should work with glasses that promote gaze exercises, or use a laser beam (mounted on glasses or a dedicated helmet) to guide the eyes to follow moving or stationary visual targets.

One patient said that the technology ***should use visual stimuli*** to induce isolated eye movements.

**3.2.2 Operational aspects (n=28)**

Patients said that the technology should be ***adaptive, gamified and motivating*** (N=5), while physical therapists focused on it being ***gamified and motivating*** (N=6)***.*** Patients wanted the technology to initiate progression in exercise difficulty level and to be able to challenge the user in a gamified manner. Physical therapists suggested having multiple difficulty levels, though which one progresses with accumulated points, using competitive elements, and creating interesting, innovative activities.

Both groups, primarily physical therapists, noted the importance of ***the ease of use*** (N=7) of the technology.One patient explained that the technology should be modified for older individuals (e.g., using large screens). This aspect was stressed more by physical therapists, who stated that the technology should be easy to operate and user friendly.

Physical therapists stressed the requirement that the technology should be ***safe and reliable*** (N=5). For example, if the technology challenges patients' postural control, then safety accessories, such as suspension bands, should be considered. Additionally, they stated that the technology should be trustworthy and reliably store the user data over time.

Physical therapists noted that they would also like to be able ***to control and access the exercise platform remotely*** (N=4). They explained that this would enable them to follow up on patients remotely. Also, they mentioned that telemedicine technology appears to be beneficial for rehabilitation.

One patient indicated that the technology should be ***portable***, so it can be used anywhere.

**3.2.3 Bi-directional user interface (N=26)**

Both patients and physical therapists mentioned that the technology ***should provide feedback to the user on quality and quantity of exercise performance*** (N=12). Patients also noted specific aspects of feedback that should be provided. These include balance measurements and scores based on the velocity of head movements. They suggested that feedback should be provided in "real time" and that even minor changes in performance should be acknowledged.

Patients reported that the technology should be able ***to monitor both the quality and the quantity of exercise performance*** (N=7), and physical therapists reported it should be able ***to monitor the quality of exercise performance*** (N=2). Patients mentioned specific parameters that should be monitored: gait parameters, head movement kinematics and eye movements. Additionally, they recommended the use of head-mounted sensors, cameras, and image analysis techniques. Physical therapists mentioned that eye and head movements should be monitored. They also mentioned that technology should ***monitor tolerability of symptoms*** (N=2) by measuring symptoms severity and the intensity of each exercise.

The following recommendations were made by patients: (1) The interface should include ***the option of filling out an exercise log book*** (N=2) integrated into a phone app, so that patients can show their progress to the therapists during follow-up visits; (2) the interface should ***enable remote consultation with the therapist*** (N=1), meaning that patients would be able to ask the medical staff questions online if they encounter difficulties or if questions arise regarding their exercise program.

**3.2.4 Potential benefits (N=2)**

According to two patients, the technology should provide users two main benefits- ***improved clinical outcomes*** (N=1) and ***shorter exercise sessions*** (N=1), as PA37 said: "… in the end, the question is: do we feel better after [completing] the exercises … [e.g., if] I feel I can walk with more confidence and less dizziness".

**3.3 The advantages of using SARs in the context of vestibular rehabilitation**

**3.3.1 Motivates and enhances adherence (N=25)**

The potential to increase motivation and adherence to perform exercises was perceived as one of the major advantages of SARs. It appears that this advantage was related to certain perceptions about what SARs are and what they are capable of:

1. ***SARs are interactive*** (N=16). SARs can also be ***informative***, according to patients, by providing instructions, demonstrating how the exercises should be performed, and guiding users on how to perform them appropriately. They also stated that SARs are useful for pacing head movements (which is important for gaze stability exercise), measuring the duration of each exercise, and encouraging the user to continue, even when it is difficult and unpleasant. Physical therapists, however, focused on other aspects of interaction with SARs, including maintaining personal relationships, maintaining eye contact, and giving the impression of doing the exercises together. One therapist said that "being seen by someone, even a robot" is important for increasing motivation, and may also help alleviate loneliness (referring to people who may experience loneliness in parallel with the rehabilitation process). Others have suggested SARs can be useful in the clinical setting if used by children, or that placing SARs in a physical therapy room, where they can be seen by all, can provide patients with an engaging experience.
2. ***SARs are novel*** (N=5). Patients thought that the novelty and ***physical prominence*** of SARs would contribute to user engagement and motivation. Physical therapists described SARs as "new and different" or even "a toy", and mentioned that they create a sense of curiosity due to their novelty.
3. ***SARs are potentially useful for patients with cognitive decline*** (N=3). This was raised only by physical therapists. PT21 explained:"… it can be very good for patients with mild cognitive impairment, as a treatment in the clinic, because it can make them track [moving] objects. They could do it naturally, as they see the robot moving, they will follow [its movement], without… having to explain the exercise to them. It could be a way to generate cooperation with people who are less cooperative"*.*
4. ***SARs can serve as "exercise reminders"*** (N=1). One physical therapist suggested that SARs may be helpful by inviting users to exercise, thus reminding them to do so.

**3.3.2 Provides feedback (N=15)**

Patients and physical therapists both noted that ***providing feedback to patients*** (N=14) is another potential advantage of SARs. Specifically, they were interested in feedback on correct or incorrect exercise performance, which can improve care between follow-up sessions with the therapists. According to physical therapists, patients would benefit from feedback if SARs could provide it after tracking eye movements and head-movement velocity, as well as on exercise performance, including dose and number of movements. They explained that these types of feedback could increase patients' self-confidence and provide a sense of control and engagement.

**3.3.3 Optimizes healthcare practice (N=6)**

Two patients suggested that SARs can ***improve access to rehabilitation and rehabilitation efficiency***. They explained that if SARs can be accessed remotely by the users, thus serving as a tele-rehabilitation platform, this will help relieve some of the burden within the healthcare system.

Physical therapists said that SARs can improve healthcare practice if they are ***time saving*** (N=3). They explained that SARs may be able to assist the medical staff with general tasks, as well as provide extra practice time for patients without the supervision of their therapists. They noted that it is important that SARs would be ***safe to use independently by patients*** (N=1)

**3.3.4 Beneficial for specific populations (N=6)**

Several patients indicated that SARs might be more beneficial to some populations than others: ***older adults*** (N=1)**; *children*** (N=1)**; *patients with special needs*** (N=1)*;* ***lonely people*** (N=1)**; people who are less motivated** (N=1)**;** and **people who are visually sensitive to screens** (N=1). One patient (PA35) referred to an earlier discussion regarding exercising using phone applications: "…many people [in this discussion] noted that it would be much easier to practice with a screen… I have a problem, which is that screens make me dizzy, and I know that there are people who have the same problem with television screens, computer screens, phone screens, etc., so for them, practicing with a screen would be difficult; so I think that for people like me, who get screen-dizzy, the robot can help … because this way, you can get feedback without becoming dizzy".

**3.4 The likelihood that patients with vestibular disorders and vestibular physical therapists will use SARs**

The online survey was completed by 36 participants: 15 patients and 21 physical therapists. The median likelihood of patients using SARs was estimated by patients at 50% [0%-100%] and by physical therapists at 60% [20-100%]. The median likelihood of physical therapists' using SARs was estimated to be 70% [10-100%].

**3.5 The positive and negative aspects of using robotic technology in the context of vestibular rehabilitation**

Among patients, negative aspects were mentioned more frequently (N=12) than positive aspects (N=7). The physical therapists, on the other hand, have emphasized more positive aspects (N=19) than negative aspects (N=9). These are detailed below.

**3.5.1 Positive aspects (N=26)**

Both groups referred to SARs as ***"Cute and amusing"*** (N=11). Words such as "cool" and "funny" were also used in this context. Patients also indicated that an interaction with SARS: (1) will likely ***increase motivation*** (N=2), assuming they will have the ability to talk, encourage and monitor exercise performance; (2) may ***help overcome loneliness*** (N=1), as explained by PA31:"… Sometimes I feel really lonely… I can barely drive long distances, so if it was in the form of a dog or something like that, it's nice. I mean, its interaction, even though it’s a robot. Psychologically, I have an interaction with someone or something, which encourages me to do the exercises…"; (3) ***can be helpful for home use*** (N=1); (4) ***can help overcome boredom while exercising*** (N=1).

Physical therapists noted that: (1) a SAR designed to appear human-like or pet-like ***may be perceived as more friendly*** and less machine-like, which ***can increase user engagement through the use of affect*** (N=2). XXxx explained that when a robot resembles an animal, it may be likeable and less intimidating than a human or a machine that gives feedback without the pet-like appearance. The use of human-like appearance, XXxx explained, may be beneficial since it may simulate the sensation that the “human” is really satisfied or dissatisfied with the users’ exercise performance;(2) interaction with SARS ***can elicit positive emotions*** (N=2) among the users; (3) SARs are ***physically embodied*** (N=2). This was perceived in an advantage, when compared to using phone applications or computer screens; (4) SARs ***provide feedback*** (N=2), which was considered to increase self-confidence and perceived as meaningful, regardless of whether the feedback is from a person or from a machine; (5) SARs can have ***the ability to initiate interaction*** (N=1) with the users; (6) SARs can have ***the ability to make eye contact*** (N=1), a trait that was perceived important for human communication.

**3.5.2 Negative aspects (N=21)**

The negative aspects regarding the use of SARs which were noted by patients: (1) ***disbelief in the long-term success of the device*** (N=6). Some patients were doubtful whether interacting with SARs can increase their motivation to do more exercise. Others indicated that they would use the SAR once or twice and then ignore it (novelty effect), or that the SARs seemed to be nothing more than a gimmick; (2) SARs are ***designed in a manner that is exaggerated beyond what is necessary to accomplish the goals of vestibular rehabilitation*** (N=3).In other words,rather than relying on sophisticated technology, such as SARs, simpler methods can be employed, such as using phone apps to provide feedback and reminders; (3) SARs ***can be noisy*** (N=2); (4) a person's ***motivation to exercise should not rely on an external device*** (N=1),but rather be derived from within.

The negative aspects which physical therapists mentioned were: (1) SARs ***can be boring or annoying at some point*** (N=4); (2) SARs ***might be perceived as childish or 'awkward'*** (N=3), especially by older adults, who may then not take the exercises seriously; (3) it is possible that ***some patients will be deterred if SARs will initiate physical contact*** (N=1), which was described as "creepy"; (4) ***emotional interaction with SARs feels fake*** (N=1), as described by one physical therapist. It was therefore recommended by the physical therapist that SARs refrain from asking patients some questions, such as how they are feeling.

**3.6 Considerations of using SARs in the context of vestibular rehabilitation**

Participants raised the following considerations as a basis for the decision on whether or not to use SARs for vestibular rehabilitation:

**3.6.1 Cost and effectiveness (N=28)**

The balance between ***cost and effectiveness*** (N=18) was one of the major considerations that was mentioned by both groups. They explained that for SARs to be useful to their users, their price should justify their use by improving clinical outcomes more than existing methods or technologies, such as computer software or online therapy sessions. One physical therapist noted that borrowing a SAR rather than purchasing it may be a good alternative, as she expected that SARs will be expensive.

Patients stated that ***the added benefit of SARs*** (N=7), such as shortening treatment time, providing corrective feedback, and reminding patients to exercise, would factor into their decision. They indicated that if the use of SARs for vestibular rehabilitation is ***supported by evidence-based research*** (N=3), they will consider using them; specifically, they wanted to see scientific evidence for the efficacy of SARs in shortening the needed treatment duration and leading to better clinical outcomes than standard care.

**3.6.2 Operational and design aspects (N=24)**

***The technical simplicity*** (N=9) involved in using SARs was another major consideration for both groups.Participants said they will consider using SARs depending on: the ease of use, the time needed to operate them, the time needed to understand how to use them, and the method for collecting and analyzing data. Additionally, both groups mentioned the ***physical characteristics of SARs*** (N=6) as a consideration, including whether the SAR is mobile or stationary. A number of factors were considered to be affected by this, including the size and weight of the device being stored at home, its ability to be adjusted for different user positions (sitting or standing), and whether it could be transported outside the home.

Patients also noted ***the*** ***charging method*** of SARs (N=1)- wireless vs. wired, and the frequency and time required for charging the device; the ***availability of SARs and the bureaucracy involved in obtaining them*** (N=1).

Physical therapists also mentioned: (1) ***the ability to operate and access the SAR remotely*** (N=5): remote access by clinicians can allow tailored treatment plans to patients to be adapted remotely, and provide clinicians with information on the patients' performance between follow up meetings; (2) ***reliability*** (N=1)- the ability to work without technical issues; (3) ***safety*** (N=1)- the ability to use SARs by users without harming or endangering them.

**3.6.3 Choosing the right patient / patient characteristics (N=23)**

While patients referred to this aspect less frequently (N=4), a significant area of focus for physical therapists (N=19) was selecting patients who are likely to benefit from SARs.

From the patients' perspective, being part of a specific populations can be an important consideration for using SARs: (1) ***children were perceived as more likely to benefit from SARs than older adults*** (N=2). They explained that SARs can act as motivators of exercise for kids, whereas older adults may prefer using phone applications instead; (2) ***patients who are desperate from their medical condition would be willing to try anything*** (N=2).

The physical therapists said they would consider utilizing SARs as part of the rehabilitation process depending on several factors: (1) ***patient’s diagnosis and medical background*** (N=8)- intact cognitive functions and judgment, and the expected duration of the rehabilitation. For example, PTxx noted that the long rehabilitation process for PPPD (Persistent postural perceptive dizziness) makes SARs suitable for this diagnosis, and that the relatively short rehabilitation process for vestibular hypofunction makes SARs less suitable for this condition; (2) ***the extent to which a patient is mobile*** (N=5), or more specifically, the inability to attend a clinic appointment would make the use of a SAR more relevant for this population; (3) ***technological skills*** (N=3) the patients must feel comfortable with using sophisticated technological devices; (4) ***low compliance with standard treatment*** (N=2); (5) ***space*** (N=1) having enough space at home to accommodate the SAR.

**3.6.4 Necessary SAR features described by patients (N=5)**

Patients said they would positively consider using SARs if they: (1) ***provide feedback*** ***on exercise performance*** (N=2); (2) ***are gamified and enjoyable*** (N=1); (3) ***make the exercise more challenging*** (N=1); (4) ***enable continuous interaction with the therapist*** (N=1), as a form of tele-medicine.

**3.7 The use of SARs for vestibular rehabilitation raises a number of concerns**

**3.7.1 Concerns relating to technology and the operation of SARs (N=41)**

***The technical complexity*** (N=22) associated with the use of SARs was a concern for both groups. They noted that SARs might be too complex to use, thereby consuming more time than exercising without them, and that their complexity makes them unsuitable for older adults or those who are technophobic. Physical therapists also added that continuous technical assistance may be necessary. They stressed that SARs should be very intuitive to use, work quickly, and not require passwords to be entered in order to start using them.

The ***durability of the SARs***for short- and long-term use(N=8) was another concern for both groups, as it might be easily damaged.

Additional concerns were mentioned only by patients, and were related to: (1) the ***price of SARs, availability of technical support & warranty* (**N=6)- SARs might be too expensive and health insurance companies may not cover the costs, thus preventing some people from accessing them. In addition, there was concern that there would not be sufficient technical support available when needed or that the warranty would not cover damages; (2) ***the physical characteristics of SARs-*** ***noise, size and mobility*** (N=5).Some patients were concerned that SARs might be too noisy, too large, or difficult to transport outside the house, thus prohibiting them from doing the exercises elsewhere, such as at work.

**3.7.2 Safety concerns (N=27)**

Physical therapists mentioned ***safety concerns*** more frequently (N=20) than patients (N=7). Both groups mentioned concerns related to ***injuries that can be caused to patients*** (N=17), such as direct injuries resulting from the movement or malfunction of SARs. Physical therapists were concerned that patients might fall while using SARs, because of the nature of the vestibular rehabilitation exercises. A number of situations have been referred to as being riskier, such as the use of SARs without supervision, the use of SARs for balance exercises, or the use of SARs that are too mobile (e.g., SARs that are able to move on wheels inside the house).

Another concern of both groups was that SARs can lead to ***persistence in practice regardless of the patient's state***(N=10). An example given by a patient was that SARs may not be able to recognize the users' state and continue to encourage them to exercise despite their discomfort. Other patients added that SARs may give incorrect instructions for exercise or may not be properly calibrated, which can result in more harm than benefit, such as cervical disc herniations. Physical therapists were concerned about the amount of exercise given by the SAR, as excessive exercise could worsen symptoms, result in neck pain or even result in falls.

**3.7.3 Concerns about the therapeutic use of SARs** (**N=22**)

Both groups, especially physical therapists, were concerned that using SARs ***might get 'boring' with time*** (N=14). In terms of the novelty effect, they explained that using SARs for rehabilitation can seem fun at first, but eventually patients may cease to use them due to loss of interest or a lack of variety of what SARs can do.

***Ethical concerns*** (N=6) were also raised by both groups. Patients were concerned about privacy (access to personal data), dependence (loss of autonomy) and trust. One patient (PA28) expressed doubts regarding whether he could truly trust the robot to adjust to his therapeutic needs: "Is [the robot] doing [the exercise demonstration] at the right speed? Can I trust [it]? Does [the robot] know me, and what is good for me? … I know what is the [head movement] speed that is good for me, [but] I don't know whether the robot knows that speed. I assume it is different for different people, depending on the [rehabilitation] stage they are in, so I doubt its effectiveness". On the other hand, physical therapists had a different ethical concern, that robot can potentially replace the human-human interaction that is considered important by them in medical care. One physical therapist (PT15) expressed his hesitation towards human-robot interaction in the clinical setting; he noted that watching the XX video made him feel uncomfortable, since he is concerned about communication becoming less personal, with less emotional interaction. He said that he would really like to see a robot that helps with vestibular rehabilitation, but wanted to interface it with other (not robot-based) types of rehabilitation, so that the human-human interaction will not be replaced.

Two additional concerns were expressed by patients, regarding the therapeutic use of SARs for vestibular rehabilitation. One concern was that ***SARs are potentially ineffective*** (N=1), and another concern was that there seems to be ***not enough demand for SARs*** (N=1): it may not be cost effective to develop SARs since not many people necessarily suffer from vestibular problems.

**3.8 Technology preferences and suggestions for vestibular rehabilitation**

The patients and physical therapists shared their ideas regarding how vestibular rehabilitation technologies, which are not necessarily SARs, should be designed. There is some overlap between these ideas and those mentioned in response to previous questions. These suggestions are summarized in **Figure 2**, and fell into three main categories:

**3.8.1 Operational aspects (N=37)**

Both groups indicated the following preferences: (1) the technology should be able ***to integrate with external devices or accessories*** (N=9), e.g., phone applications, virtual/augmented reality devices, smartwatches, drones or medical equipment, such as blood pressure measure devices; (2) the technology should use ***reminders for exercise*** (N=7); (3) operating the system should be ***intuitive and simple*** (N=4).

Patients added that they want the technology to include ***built-in sensors*** (N=5), such as tracking devices for eye or head movements, or cameras that can track gait and posture parameters. Other suggestions by patients were to include ***a voice activation feature*** (N=1) similar to "Siri", and that the technology ***should provide their therapists with data*** (N=1) using cameras, to monitor exercise performance.

It was also suggested by physical therapists that the technology ***should enable remote access for the therapist*** (N=6) in order to track exercise data, modify or add exercises, as well as alter the rhythm of head movements. Physical therapists also recommended the technology: (1) be ***wireless*** (N=2) and powered by batteries; (2) ***be used either in the clinic or at home*** (N=1); and (3) be able to ***physically support the patient to maintain safety*** (N=1), in cases where the patient's balance is disrupted while exercising.

**3.8.2 Interaction with the patient (N=30)**

According to both groups: (1) the technology should be ***responsive to patient’s state and preferences*** (N=9). That is, it should adjust its instructions to the specific needs, symptoms and limitations of the user at each time point. One patient suggested it should be able to recognize emergency situations, such as falls, and another suggested that it should detect whether the user is available for exercising by detecting when the user returns home;(2) the technology should provide them with ***a variety of feedback*** (N=9): feedback on exercise performance and progress, negative feedback and alerts when progress is not as anticipated. At the same time, physical therapists noted that the amount of feedback to patients should be limited, as it is time-consuming; (3) interaction with patients should be ***communicative and playful*** (N=5). Patients described how the interaction with the user should be 'amusing' or 'gamified'. According to physical therapists, the technology should be able to 'play' with the patient, and should respond when touched, as in the case of the SAR that was shown in the video.

Patients made two additional suggestions: (1) the technology should provide users with ***demonstration of exercises and guidance*** (N=4) on how to perform their exercises in accordance with what the therapist prescribed; and (2) the technology ***should not replace self-responsibility*** (N=1) to follow through with the rehabilitation exercises.

Physical therapists stressed that the technology ***should not replace interactions with the therapist*** (N=2), as it should be used in conjunction with follow-up visits with the therapist.

**3.8.3 Design (N=29)**

The participants were not in full agreement as to whether the technology should be ***mobile or stationary*** (N=7). The trend was to prefer mobile technology, as it could be used to follow patients who are doing walking exercises, either to provide instructions or to monitor their gait parameters. The two groups also indicated that they would like the technology ***to project lights (e.g., a laser beam on a wall) to guide practice*** (N=6).

Patients suggested they want the technology to have ***varied sounds and music*** (N=4). In their opinion, background music should be played and there should be different voices which do not sound "too robotic". Furthermore, patients suggested the design should include ***a variety of functionalities to maintain interest over time*** (N=3). The possibility of selecting between different characters that would guide one's exercise was one example given in this context. Additional suggestions by patients were to ***use voice instructions***(N=1) for exercise rather than just text, and to develop a technology that ***does not serve as*** ***"nothing more than a gimmick"*** (N=1).

The physical therapists also discussed the design of robotic technology, and proposed that several configurations should be available- **human-like/animal-like/atypical (unlike familiar shapes)** (N=7).

**4. Discussion**

This study examined how patients with vestibular disorders and vestibular physical therapists perceive the main features needed from technology for vestibular rehabilitation, using a socially assistive robot as a test case. To our knowledge, this is the first study to attempt such an analysis using focus groups. Several well-established models have been described in the past to shed light on how technology is accepted. Our qualitative data from vestibular physical therapists and dizzy patients together with these models can be applied in the design process of technologies for vestibular rehabilitation – be they in the field of HRI or HCI.

According to the Technology Acceptance Model (TAM) (Davis, 1985), which has been extensively used to understand human behavior with regards to technological innovations (Marangunić & Granić, 2015), the motivation (an intention to use) to actually use a system (a response), relies on its features and capabilities (a stimulus) (Chuttur, 2009). The perceived ease of use and perceived usefulness of the technology are the two primary factors influencing one's decision to adopt it (Davis, 1985; Marangunić & Granić, 2015). Indeed, we found that both patients and physical therapists consistently emphasized these factors in our study, in terms of technical simplicity, cost-effectiveness and potential clinical benefits for users. Extensions and modifications to the TAM consider other external factors as well(Burton-Jones & Hubona, 2006; Marangunić & Granić, 2015), such as contextual factors(Kothaneth, 2010) and usage related measures(Szajna, 1996). In our study, contextual factors were primarily related to the setting in which the technology can be applied (e.g., home vs. clinic), and the type of patients that would be using the technology (e.g., pediatric vs. geriatric, patients with acute symptoms vs. patients with chronic symptoms). The usage factors outlined in our study were mainly described as desired platforms (such as phone applications), which would provide feedback on exercise performance, and facilitate remote and continuous communication between patients and their therapists. In that context it is important to note that feedback to patients should on the one hand be meaningful and helpful, but at the same time limited in content and frequency, so as not to overwhelm them (Fruchter et al., 2022).

The results of our study can also be viewed in light of the Unified Theory of Acceptance and Use of Technology (UTAUT) model(Venkatesh et al., 2003). According to the original model, users' behavior is based on a behavioral intention, which is directly affected by the following: *performance expectancy, effort expectancy, social influence,* and *facilitating conditions*. An extension to this model(Venkatesh et al., 2012), includes additional direct factors: *hedonic motivation, price value* and *habit*. Other factors that can indirectly affect behavioral intention include age, gender, experience and voluntariness of use.

*Performance expectancy* is defined as the users' belief that the system will help them in their working environment. Among the main expectations from vestibular rehabilitation technologies were the ability to save time, monitor exercise performance, and improve clinical outcomes in an engaging and safe manner. *Effort expectancy* is defined as the ease with which the system can be used. Patients and physical therapists repeatedly pointed the ease of use as a major requirement, while overcomplexity in operating the system was considered a "deal breaker" for using the technology; this sentiment echoes previous reports in the broader context of using technology for rehabilitation [ref]. *Social influence* is related to what others may say about whether an individual should use or not use the new system. Interestingly, this factor was not mentioned by the participants in our study as an issue with novel technologies for vestibular rehabilitation. *Facilitating conditions* refer to how a person believes that there is an organizational and technical infrastructure to facilitate the utilization of the system. The participants mentioned a need for ongoing technical support, warranty coverage, as well as the possibility of purchasing or borrowing the system from the healthcare organization. *Hedonic motivation* is related to how engaging the technology is. Participants discussed the possibility of gamifying exercise in novel technologies for vestibular rehabilitation. *Price value* was described in terms of cost-effectiveness of using the system. *Habit* is related to the routines of using the technology. Some participants noted that people have become accustomed to the use of phone applications and external accessories, such as smartwatches, and so this may be a preferable platform for some users. Age is an important indirect factor that should be taken into account, as vestibular disorders affect both children and adults(Hall et al., 2022b; Neuhauser et al., 2005b; Neuhauser & Lempert, 2009). Participants in our study noted that the technology should enable an enjoyable experience for all age groups, while still being accessible to older adults who may need more time to become familiar with it. It is recommended to consider other indirect factors(Bradwell et al., 2021; Flandorfer, 2012), including gender(Tanqueray et al., 2022), although this was not raised by the participants in our study.

Regarding the design of SARs for vestibular rehabilitation, identifying the patients who would benefit most from the use of the technology is important (Feingold Polak et al., 2023). Participants in our study considered children and patients with chronic conditions as being more likely to use SARs for vestibular rehabilitation.

Some of the concerns raised by the participants regarding the use of SARs in our study have also been reported in the literature. One example is the claim that emotional interaction with SARs may feel fake. This seems to express a refusal to accept the social roles and behavior of robots, especially when it comes to companionship and relationships, which we also reported in a study with individuals with Parkinson’s disease (Kaplan et al., unpublished data), and may be related to the concept of "social uncanniness"(Hoffman, 2020). Individuals with Parkinson's disease also expressed concerns regarding a possible loss of autonomy when receiving assistance from SARs (Bar-On et al., 2023), which XX. Some authors discussed the trustworthiness of SARs, depending on their rehabilitation tasks (Kellmeyer et al., 2018; Langer et al., 2019; Schröder et al., 2023). Indeed, a key consideration when interacting with a robot on a long-term basis is trust (Langer et al., 2019). Lastly, this is not the first time that the concern of robots replacing human interaction has been raised (Dembovski et al., 2022b; Kristoffersson et al., 2011; Langer & Levy-Tzedek, 2021). In this regard, we recommend that SARs should be "applied locally" to the tasks they are designed to perform (Langer & Levy-Tzedek, 2021).

**Study limitations**

The main limitation of our study is that participants were discussing only one test case (the ClicBot robot) in the focus groups. The specific design and physical embodiment of a SAR can affect the perception of the robot’s capacity for social interactions(Deng et al., 2019). Moreover, some of the participants were exposed to SARs for the first time, hence generalizing the results is limited.

**5. Conclusions**

In this study, patients and physical therapists provided insights about the development of novel technologies that can be used to enhance adherence to vestibular rehabilitation. Although SARs can potentially be used to increase adherence, it appears that a phone application can be another suitable medium for this purpose, with less notable concerns from users. It is recommended that the platforms' core functionality include the capability of monitoring exercise performance and providing qualitative and quantitative feedback to the user. Additionally, it is important that the platform should be easy to use, safe, gamified and cost-effective. It may also be useful to include features such as reminders for exercise, sensors for tracking head movement or body kinematics, visual stimuli, and the ability to work with external devices, such as a smartwatch. Importantly, novel technologies for vestibular rehabilitation can act as a telerehabilitation platform rather than replacing clinicians, and improve communication between therapists and patients in the rehabilitation process.

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