MIXED REALITY IN SPINAL CORD REHABILITATION

'YOU NEED SOME ATTITUDE TO INNOVATE'

Author: Jessica van der Lede
June 18th, 2023
Total words: 5956

This study was conducted by a Physical Therapist in
De Hoogstraat Rehabilitation, Utrecht, The Netherlands

ABSTRACT

Background: Innovative approaches in technology, such as Mixed Reality (MR) devices, are getting their way into rehabilitation to supplement movement training. With this interactive technology, holograms are projected within the contextual real environment. In current spinal cord injury/disorder (SCI/D) rehabilitation research, the use of technology to augment physical interventions is common. However, the successful implementation of high-tech devices into rehabilitation practice during the subacute phase is challenged.

Objective: This study aimed to assess the experiences and perceptions of patients and healthcare practitioners on the usability, usefulness, and applicability of MR with the Microsoft® Hololens 2 in our rehabilitation practice and to investigate the influence of these factors on the adoption of this innovation within the multidisciplinary SCI/D rehabilitation practice in a single Dutch rehabilitation center.

Method: This explorative study assessed the implementation of MR reality within a 6-week pilot period in a multidisciplinary SCI/D rehabilitation setting. This pilot was embedded in a study with a combined approach of participatory action research (PAR) and the implementation process model by Grol & Wensing. The innovation was introduced to 12 participants: 3 multidisciplinary healthcare practitioners and 9 patients with SCI/D. With a mixed methods approach, data were collected using questionnaires, interviews, and experiential self-examination. We analyzed the process data descriptively.

Results: The following implementation outcomes were assessed; perceived ease of use (PEOU), perceived usefulness (PU), and applicability, from the patients' perspective (N=9) and healthcare professionals' perspective (N=3). Participants rated the PEOU of the system on the System Usability Scale (SUS) from 1 (strongly disagree) to 5 (strongly agree). The total score could range from 0 (low usability) to 100 (high usability) points. Patients scored the hardware and interface with 70.0 (median; IQR 7.8) points and the game applications with 75.0 (median; IQR 13.0) points. The healthcare practitioners scored the hardware and interface with 72.5 (median; IQR 13.0) points and the game applications with 82.2 (median; IQR 5.3) points. The PU was assessed with a questionnaire based on the Technology Acceptance Model (TAM), which addressed the perception that the utilization of MR will improve rehabilitation performance, related to patients, and work performance, related to healthcare practitioners. All 6 questions used a 6-point Likert-type scale (1= strongly disagree to 6= strongly agree). Both generally increased after the pilot period. All interviewed participants (N=6) perceived good applicability of MR in their context, based on the FAME (feasibility, appropriateness, meaningfulness, effectiveness, and economic evidence) framework elements. Through focus groups, there has been continuous analysis of barriers and facilitators to change to which actions for implementation have been adapted. As a result, among other things, a knowledge document has been developed to support clinical reasoning in relation to the possibilities of MR application.

Conclusion: Patients with SCI/D and their healthcare practitioners had an overall positive attitude, i.e. perceived usability, and usefulness, towards the use of MR, which is one of the most important factors for the adoption of an innovation in clinical practice. MR with Microsoft's® Hololens 2 was found to be applicable for the targeted group in this specific rehabilitation setting, based on the FAME framework elements. These factors are therefore considered facilitators for the adoption of MR in the multidisciplinary SCI/D rehabilitation practice. At the same time, we gained experience in using a research approach that allowed us to focus on the attitudes and associated necessary process of behavior change of our end users, design materials that support implementation within group collaboration, and gain insight into possible types of MR applications in this specific setting. We provided a start that allows us to continue with implementation activities, to aim to ensure sustainable use of MR in our usual care practice to help maintain intensive movement training during the subacute rehabilitation phase.

Keywords: Spinal cord injury/disorder, rehabilitation, Mixed Reality, usability, usefulness, applicability, participatory action research, behavioral change, implementation

INTRODUCTION

Rehabilitation after the onset of a spinal cord injury/disorder (SCI/D) is often a long-term process. Damage to the spinal cord leads to many profound physiological changes resulting in temporary or permanent loss of the motor, sensor, and autonomous functions.[1] In the sub-acute phase, targeted treatment in a multidisciplinary setting is often required.[2] De Hoogstraat Revalidatie (DHR) is one of the 8 specialized SCI/D rehabilitation centers in the Netherlands. Its multidisciplinary team offers rehabilitation to approximately 100 inpatients with newly acquired SCI/D each year.[3]

Challenge in current healthcare
Participation in a rehabilitation program in the sub-acute phase is of great importance to achieve the highest level of independence within the possibilities of functioning.[4,5] Here, intensive movement training is a high priority to maximize the restoration of function.[6,7] However, the Dutch healthcare system is experiencing great pressure due to high healthcare costs, shortages of personnel, and a high workload.[8] This challenges the assurance of intensive movement training during this phase of rehabilitation. The Dutch Integral Care Agreement, which aims for better patient-centered care in 2024, suggests "the use of technology for targeted support of healthcare professionals" [8(p.65)] as a solution for this expected bottleneck. DHR feels the need to respond to this inevitable change in the landscape of healthcare by prioritizing continuing development through the implementation of new technologies where possible.[9]

Mixed Reality: a novel technology
Innovative approaches in technology are getting their way into rehabilitation to supplement training with an intensive character.[10,11] One of these advancements was the introduction of Mixed Reality (MR). With this interactive technology, virtual elements (holograms) are projected within the real contextual environment with MR glasses like the Microsoft® Hololens. MR is a promising technology in the field of rehabilitation and has the potential to contribute to the intensification of movement training to maximize the restoration of function.[10,12]

Potential in rehabilitation
In current SCI/D rehabilitation research, the use of technology to augment physical interventions was found common.[13] However, the successful implementation of high-tech devices into multidisciplinary rehabilitation practice is challenged, as they were reported as infrequently or rarely used.[13,14] The intention to use a product depends to a large extent on the attitude of the users, which is mostly determined by the perceived ease of use (PEOU) and the perceived usefulness (PU) that users have towards a product and have therefore a great influence on the adoption rate.[15] To evaluate the translational potential of MR in our SCI/D rehabilitation practice we needed to elicit input from end-users. Therefore, this small-scale exploratory study aimed to investigate the novel area of MR adoption in our multidisciplinary SCI/D rehabilitation practice, where the findings can be used as guiding principles for implementing this innovation into our usual care practice. The research question of this study is: What are the experiences of patients and healthcare practitioners on the usability, usefulness, and applicability of MR use in our multidisciplinary SCI/D rehabilitation practice and how do these factors influence the adoption of this technology-based innovation in this setting?

METHODS

Design

Exploratory evaluation studies can be designed in different ways. In the field of quality improvement and knowledge implementation, most are close to routine practice.[16] This empowered the choice for a Participatory Action Research (PAR) approach, which enabled us to learn from and improve real-world practice with the involvement of patients and interprofessional healthcare practitioners with specific practical knowledge in the actual setting. [17]

Setting
Driven by changes in the healthcare landscape, DHR aspired to increase the adhocracy culture in the organization and showed to be an early adaptor in the field of engaging MR in rehabilitation. This allowed the conduction of this 'bottom-up' exploration study with attention to innovation, motivation, collaboration, and creative ideas with an interdisciplinary character.

Context
The social, economic, and organizational contexts were evaluated based on an actor/force field analysis during each PAR phase. To structure the different roles of all stakeholders we positioned them schematically in a ring of influence.[18] With this, we determined their influence and role in cooperation within the project.

PAR Team
At the beginning of the PAR process, we established 2 stakeholder groups, the focus group, and the operator group. Both were guided by the project's main researcher, a physical therapist experienced with SCI/D rehabilitation and experienced using MR. All stakeholders focus group stakeholders were recruited based on an actor/force field analysis and had substantial experience with MR using the Microsoft® Hololens 2 in a rehabilitation setting. This group consisted of 1 patient, 1 physical therapist, 2 occupational therapists, a healthcare innovator, and a technician.

With the recruitment of the healthcare practitioners for the operator group we aimed for a diverse group composition that would sufficiently represent the entire team of the SCI/D department, based on profession and results of the conducted De Caluwé and Vermaak color analysis.[19] This method provided insight into the complexity and dynamics between different ways of thinking about change within the group. This multidisciplinary group consisted of a physical-, occupational-, and sports therapist, with minimal to no experience with the use of MR. Participation of 3 SCI/D patients, representing different severities of injury like tetraplegia and paraplegia, with or without the ability to active weight bearing, completed this group.

An advisory group, consisting of a manager, 2 post-doc researchers, and a rehabilitation doctor, provided peer support with review, advice, and feedback.

Patients

Patients with a SCI/D receiving in or outpatient multidisciplinary rehabilitation treatment during the recruiting phase for the study were eligible for inclusion if they were 18 years or older and could raise at least 1 arm and hand to eye level. The use of a haloframe and prescribed bed rest at the onset of the study were exclusion criteria.

Intervention

We used the Microsoft® HoloLens with a variety of applications, created by HoloMoves®, that elicit physical activity. The intervention entailed a 6-week pilot period, where the operator group used MR in their multidisciplinary rehabilitation treatment.

Implementation strategies

As far as users are concerned, attitude and the intention to behavioral change are related to the consideration of whether or not an innovation is feasible within their practice.[15,20] To guide this process of behavioral change, we combined the implementation theory of Grol and Wensing[21] with the 3 phases of PAR, namely the thematic phase, crystallization phase, and example phase.[22] This enabled us to fit appropriate implementation strategies accordingly.

Procedures

The study had a duration of 8 months. The development of the concrete study proposal started in October 2022. After the analysis in the thematic phase, the PAR team was sorted together by the end of November 2022. The crystallization phase, characterized by designing the pilot, was completed at the end of January 2023. The pilot period, related to the exemplarian phase, ended in April 2023. Followed by data analyses, the evaluation was finalized at the end of May 2023.

Ethics and consent

This quality improvement study was part of the usual care. All participants (N=12) were informed about the study by the researcher and provided written informed consent prior to initiating the study. All assessments and interviews were conducted on voluntary bases and results were pseudonymized. Voice recordings and study-related documents were stored in a secured internal digital network space.

Trustworthiness

Various strategies have been applied to ensure the trustworthiness of the study. The data collection had a period of several weeks and methodical triangulation was achieved. Analysis of all data was peer-reviewed by 2 experienced researchers. An audit trail that includes the logs, completed questionnaires, minutes of all meetings, audio recordings, English and Dutch interview guides, and transcripts of the interviews is available.

Group meetings

The focus group had twice a 60-minute meeting in the thematic phase. Ideally, a strategy that aims to change clinical practice is designed based on an analysis of barriers and facilitators to change.[17] Therefore, the focus group conducted a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis. The DESTEP[23] factors and 7S-model[24] elements were used to facilitate a broad point of view. Through group discussion and joint execution, the items with the highest risk got clustered into themes. In the second meeting, they used the mindmapping technique to get insight into all influencing topics per theme.

The operator group had five 60-minute meetings within the crystallization and exemplarian phases, two of which were with patients. For this reason, the first meetings were aimed at increasing knowledge among the practitioners. This was needed before they were consciously competent to introduce MR to the patients. We used a topic list, based on the self-report Implementation plan tool of ZonmW[25], to gain insight into the vision of healthcare practitioners toward rehabilitation technology. Within the crystallization phase, the 3 mind maps, created by the focus group, got analyzed through joint discussion and served as an organizational instrument to determine and define the preconditions needed to start the pilot period. We used elements of the PDCA[26] improvement cycle to perform actions and adjust and improve the deployment method accordingly.

Data collection and analysis

In this study, we used a mixed methods approach to gain a comprehensive understanding of the adoption of MR. Data collection and analysis were accomplished concerning the available time and resources and included the use of questionnaires, experiential self-examination, and interviews. We analyzed the data using Excel version 2304.

Quantitative data

The Technology Acceptance Model (TAM) states that a user's attitude, which includes the perceived ease of use (PEOU) and the perceived usefulness (PU), has the most influence on the adoption rate of a new product.[15] This model is one of the most widely used adoption theories in studies like this.[20] To assess the PEOU of MR among all participants we used the System Usability Scale (SUS).[27] To describe how and when users will use a new technology based on PEOU. We modified the Dutch version[28] into 2 variants, one for the hardware and interface of the Microsoft® HoloLens 2 and one for the game applications. The SUS consists of 10 questions, each rated on a 5-point Likert scale (1= strongly disagree to 5= strongly agree). The total score could range from zero (low usability) to 100 (high usability). A score of 68 or higher is considered above average.[27]

To assess the PU we used a questionnaire based on the aforementioned model, which addressed the perception that the utilization of MR will improve rehabilitation performance, related to patients, and work performance, related to healthcare practitioners. All 6 questions used a 6-point Likert-type scale (1= strongly disagree to 6= strongly agree). All participants were encouraged to add any additional comments in the field provided. We reported the outcomes with the use of a frequency table and used the additional comments for clarity if needed. We assessed both outcomes twice within the exemplarian phase to discover whether there was a change of perception after a certain time of practice.

Qualitative data

We obtained perspectives on the application in practice from semi-structured interviews with members of the operator group (N=6). The predetermined thematic interview guide was developed based on the 5 elements of the FAME (Feasibility, Appropriateness, Meaningfulness, Effectiveness, Economic Evidence) framework.[29] This, was to ensure the interview questions offered a comprehensive exploration of the perceptions on applicability within the multidisciplinary rehabilitation practice. All face-to-face interviews were audio recorded, conducted, and transcribed verbatim by the main researcher. For the 2-step descriptive data analysis, we first applied data reduction to achieve meaningful text fragments, by eliminating text that had no direct relation to the question asked. Secondly, we conducted a horizontal analysis. This allowed us to be able to make connections between the perspectives of the interviewees within a heterogeneous group.

The healthcare practitioners reported the treatments with MR use in personalized logs, following the DOKA method (Dutch acronym for purpose, observation of current functioning, clinical reasoning, and actions). These logs supported experiential self-examination and served the purpose of process evaluation through reflection on their real-world practice.

RESULTS

The results are presented in 2 sections. In the first section, we described the key activities involved within the 3 phases of PAR. In the second section, we described the analysis of the results of the implementation outcomes; the usability, usefulness, and application in rehabilitation practice.

Study sample and response rates

The study started with 12 participants: 9 patients and 3 healthcare practitioners (Table 1). However, 2 patients discontinued participation prematurely due to health reasons and early cessation of inpatient rehabilitation, respectively in weeks four and five of the pilot period and therefore completed only the first questionnaires administered. All other participants completed the 6-week pilot period and all questionnaires. All operator group participants completed the interview.

Table 1. Participant demographics

ID	Age	Neurological level/ AIS grade	Participating in operator group
P1	65	C2 AIS C	N
P2	26	C3 AIS A	N
P3	80	C4 AIS D	N
P4	49	Th1 AIS C	N
P5	62	C5 AIS D	N
P6	27	T11 AIS C	Y
P7	38	C5 AIS B	Y
P8	50	CIDP	Y
P9	67	Th12 AIS D	N
ID	**Age**	**Profession**	**Participating in operator group**
H1	30	Physical Therapist	Y
H2	29	Sports Therapist	Y
H3	56	Occupational Therapist	Y

ID: identification participant; AIS: American Spinal Injury Association Impairment Scale; P: patient; H: healthcare practitioner; C: Cervical spine; Th: Thoracic spine; CIDP: Chronic inflammatory demyelinating polyneuropathy; Y: yes; N: No

Description of the combined implementation process

We related the three-phase PAR process to the 5 steps of the process model by Grol and Wensing.[21] Figure 1 illustrates a schematic representation of these methods combined and the related actions taken.

Thematic phase. Building relationships, determining starting positions, and identify facilitators and barriers

During this first phase, we established the focus group and the operator group. The focus group first identified experienced facilitators and barriers, based on their user experiences with MR. The facilitators, labeled as strengths, were increased motivation to exercise, support implicit learning with an external focus, ownership of required devices, sustainable innovation, the organization as an early adapter, applicable at any age, and the increasing patient demand for the application of new tools.

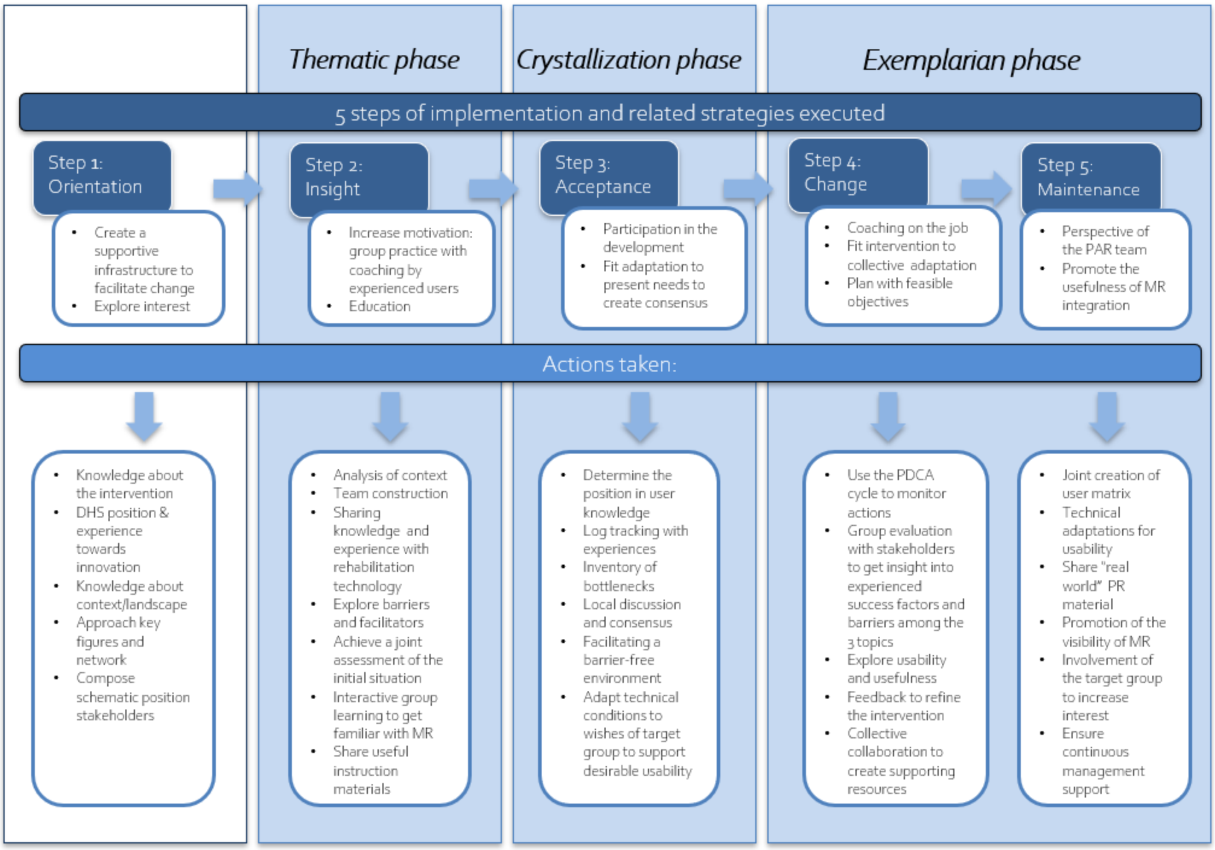

Figure 1. Combined implementation and operationalization process

Due to limited time and resources, the focus group unanimously agreed to perform an impact score assessment of the items categorized as internal weaknesses only, to turn these barriers into facilitators where possible. Secondly, they organized these items under 3 main themes: *digital skills, accessibility, and planning.*

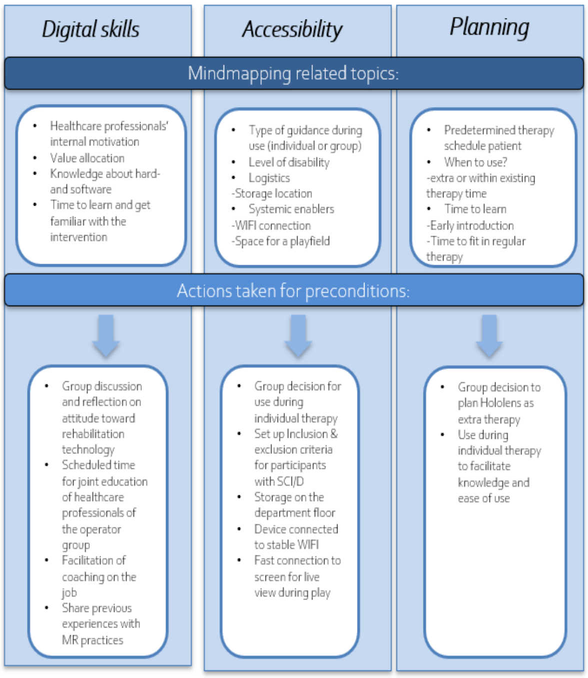

Figure 2. Main themes with related topics and actions taken

In this phase, the healthcare practitioners of the operator group got to know each other and discussed factors that would facilitate their behavioral change. Their main facilitators were taking challenges, the need to be inspired, and the freedom to discover possibilities. Here, it was preferred to act based on practical experience, so our educational strategy was characterized by a pragmatic learning style.

Crystallization phase. Draw up a plan and action planning

At the start of this second phase, the healthcare practitioners felt competent to apply the Microsoft® Hololens 2 and game applications in their treatment and to transfer knowledge to their patients. Figure 2 presents the 3 mind map topics and the required actions needed to be able to start the pilot period within the exemplarian phase. The following agreements were established to define the provisional guideline for an MR working method:

1) MR will be scheduled as an extra therapy session under the name: Hololens
2) The pilot period will have a duration of 6 weeks
3) Actions performed will be registered following the DOKA method
4) Each healthcare practitioner includes 3 patients

5) Link training content to the currently applicable rehabilitation goals
6) Possibility of coaching on the job by experienced users
7) Logistical responsibilities regarding hard- and software issues

Exemplarian phase. Implementation and process evaluation

Here, the participants executed and completed the pilot period. They gained knowledge and experience of MR use in practice and got challenged to discover the potential and possibilities within their treatment. During the execution, the operator group discussed and reflected on their explored needs to fit MR into practice and accordingly conducted the actions related to the 3 main themes. By collective agreement, changes were made to the therapy time, from 30 to 60 minutes, due to start-up and time-consuming technological operations. Also, MR as an extra therapy session needed to remain. Since, 2 healthcare practitioners noted that they were otherwise more likely to opt for functional skills training, such as a car or bed transfer, and prioritized this over movement training, even though they consider movement training an important part of rehabilitation. The operator group created jointly an MR user matrix (Annex 1) in which training skills were linked to the MR games, to provide direction to the deployment possibilities of MR and promote interdisciplinarity.

Healthcare practitioners' logged treatment reports showed similarities in the following areas: adjusting context to address specific goals, increasing the challenge component with the help of aids, use of different premises, and fulfilling a coaching role. As well as experienced problems such as the inability to fix technical issues due to external factors. All participants experienced that the allocated value seems to lie in the application of MR as an additional tool, in which it remains important to add therapeutic clinical reasoning. To be able to do so, gaining knowledge and experience with the product to improve understanding of the added value is experienced to be strongly related. Healthcare practitioners said, "By working a lot with the HoloLens and through guiding and evaluating the therapy based on rehabilitation goals, you develop new work methods" (H3) and "...and of course, I could arrange a meeting about it and be like 'hey, this is how the HoloLens works and that's how you can use it in your practice'..." (H2). With these experienced perceptions, the practitioners made their way toward the final step, maintaining change, in their process of behavioral change as a professional. Here it was important that they felt consciously competent and experienced ownership to take on further MR exposure on a greater scale. To encourage knowledge transfer to increase the willingness of the other team members to explore the use of MR within their treatment, we appointed the healthcare practitioners as 'superusers' (persons who are the driving forces for continued implementation).

Implementation outcomes

Perceived ease of use

The PEOU, measured by the SUS) by patients (Table 2, with color interpretation for more detail, see Figure 3) concerning the hardware and interface had a positive change over time from 'average' to 'good'. Despite the lower median score for the game applications at the end of the pilot period, the PEOU was overall still scored as 'good'.

Table 2. SUS results patients (n=9)

ID	Hardware and interface		Game applications	
	Wk3	Wk6	Wk3	Wk6
P1		N/A[a]		N/A[a]
P2				
P3		N/A[a]		N/A[a]
P4				
P5				
P6				
P7				
P8				
P9				
Median	65.0	70.0	77.5	75.0
IQR	7.9	7.8	9.1	13.0

[a] N/A: not available because the patient did not complete the study

SUS: System Usability scale; ID: identification; Wk: week; P: patient; IQR: Interquartile Range; N/A: not available

Despite the median scores by healthcare practitioners (Table 3, with color interpretation for more detail, see Figure 3) for hardware and game applications in week 3, which give the impression of 'good', there was 1 healthcare practitioner that scored 'poor' at the beginning. On an individual level, this participant reported the highest perceivable change in the ease of use of MR after prolonged use.

Table 3. SUS results healthcare practitioners (n=3)

ID	Hardware and interface		Game applications	
	Wk1	Wk6	Wk1	Wk6
H1				
H2				
H3				
Median	70.0	72.5	77.5	82.2
IQR	9.9	13.0	16.8	5.3

SUS: System Usability scale; ID: identification; Wk: week; H: healthcare practitioner; IQR: Interquartile Range

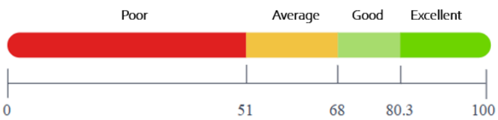

Figure 3. Color interpretation related to SUS scores

Perceived usefulness

Analysis of the PU by patients (Table 4) revealed no changes after gaining more user experience in the areas of time in executing an exercise, improving overall performance in rehabilitation, facilitating the ease of practice, and the utility of MR in rehabilitation. Compared to the start, patients perceived a greater value of effectiveness by the end of the pilot period. Several patients left comments like, because of the pleasure in movement that MR entails, they trained more intensively by shifting their focus. They endorsed perceived effectiveness and the relation with MR exercises that address specific rehabilitation goals, like "...working with the HoloLens allowed me to improve my confidence in moving, as I was distracted from my fear of moving in space" (P8). Despite the overall positive ratings in all areas, the patients less agreed on the question of whether they would add more unsupervised practice moments to their rehabilitation schedule. They clarified this with comments like, "...this wasn't an option due to the combination of my limited hand function and the accessibility of the HoloLens, and don't want to ask for help all the time" (P2), and "...the feeling of being consciously incompetent, so I still need more practice and supervision" (P3). As well as "...if it is not on your schedule, you will not do it that fast. Whereas, very stupidly, you know it has an effect and it's necessary... but anyway..." (P7) and "The first time it was suggested [by the healthcare practitioner] in week 3 like 'You can also get the HoloLens and use it yourself', but by the end of the pilot period, I found out that I had never actually done that" (P6).

After gaining more user experience over time the healthcare practitioners agreed more positively on the ability to complete tasks faster, however, overall it did not make their work easier (Table 5). This was partly related to usability issues, such as the long start-up time and the regular occurrence of technical malfunctions. They perceived less usefulness of MR in their daily practice at the end of the pilot period. Clarified by a healthcare practitioner (H2) as having experienced no added value of MR when compared to the current activities offered and felt the same goals could be achieved. Although, additional comments endorse the experienced noticeable advantages of MR use like eliciting pleasure and distraction during exercise.

Table 4. Perceived usefulness in rehabilitation by patients, numbers per score (1= strongly disagree to 6= strongly agree)

	1	2	3	4	5	6
Q1: By using the Hololens during my rehabilitation, I can perform exercises faster						
Week 3 (n=9)	1		2	1	5	
Week 6 (n=7)			1	2	2	2
Q2: Use of the Hololens would improve my performance in rehabilitation						
Week 3 (n=9)				4	3	2
Week 6 (n=7)			1		4	2
Q3: By using the Hololens I will exercise more often						
Week 3 (n=9)		2	1	2	3	1
Week 6 (n=7)	1	2	2	2		
Q4: Use of the Hololens will increase the effectiveness of my rehabilitation						
Week 3 (n=9)			2	1	4	2
Week 6 (n=7)		1		2		4
Q5: The use of the Hololens makes exercising easier						
Week 3 (n=9)				3	5	1
Week 6 (n=7)			1	2	1	3
Q6: I would find the use of the Hololens during my rehabilitation helpful						
Week 3 (n=9)				1	5	3
Week 6 (n=7)				1	4	2

Q: Question

Table 5. Perceived usefulness in work by healthcare practitioners, numbers per score (1= strongly disagree to 6= strongly agree)

	1	2	3	4	5	6
Q1: Using the Hololens at work allows me to complete tasks faster						
Week 3 (n=3)		1	1		1	
Week 6 (n=3)	1				1	1
Q2: Using the Hololens would improve my performance at work						
Week 3 (n=3)		1		1		1
Week 6 (n=3)	1				1	1
Q3: Using the Hololens would increase my productivity						
Week 3 (n=3)		1		1		1
Week 6 (n=3)	1			1		1
Q4: Using the Hololens would increase my effectiveness at work						
Week 3 (n=3)		1	1			1
Week 6 (n=3)	1			1		1
Q5: Using the Hololens would make it easier to do my job						
Week 3 (n=3)		2				1
Week 6 (n=3)	1		1	1		
Q6: I would find the Hololens useful at work						
Week 3 (n=3)		1			1	1
Week 6 (n=3)	1			1	1	

Q: Question

Applicability in rehabilitation practice

Interviewed participants described their perceptions about the applicability of MR with Microsoft's® HoloLens 2, according to the 5 elements of the FAME framework.

Feasibility. All participants perceived MR with Microsoft® HoloLens 2 as practical and practicable within the rehabilitation context and appropriate for the targeted audience. Advantages over conventional tools are experienced by patients with limited function of the upper extremities, one said, "I can't catch a ball, but I can catch and move butterflies" (P7). It seems to fit within the innovative culture of DHR despite the current efficient rehabilitation patterns, aimed at fast and functional rehabilitation, and the relatively high costs associated with technical innovations.

Appropriateness. The provided resources to enhance practical use such as a live monitoring screen, a user matrix, extended therapy time, and storage coordination were perceived as positive and facilitated the ease of use. Although, the WIFI connection in certain rooms remained limited, which had a negative influence. MR addressed training principals needed to reach personal goals given the stage and context. Although supervision and coaching by the healthcare practitioner are preferred, to assure the training addresses patients' goals through the clinical reasoning of the practitioner.

Patients experienced that exercises with MR could be adjusted along with the phases of rehabilitation and therefore their changing physical possibilities. Except for supine positions, here the possibilities within the game applications were experienced as limited.

Meaningfulness. All participants experienced MR in their rehabilitation and practice as an additional tool, to train movements that can be seen as a prerequisite to perform functional activities. To facilitate this meaningful practice the context needs to be adapted accordingly, for example by adding aids, different surfaces, or double tasks. A healthcare practitioner said about this, "Well you are trying to think even more of 'how can I make it even more challenging for people?" (H2). This resulted in exploring, and sometimes pushing, limits in physical capabilities within exercises. Patients felt that gamification (e.g. point scoring and competition by time elements) brought a nice change in their current way of exercising and it strengthened their confidence while doing so. They experienced that MR could shift their focus of attention and added enjoyment in moving. A patient explained, "So, I was doing the game and then I thought... I walked around that staircase, that practice staircase with a few steps, and I just did not hold that at all. I thought; I don't dare do that game without letting go of that staircase. That was a really nice goal for me or well, a nice goal, a nice step, so to speak" (P8).

Effectiveness. All participants shared the same thoughts about the inability to monitor progress or measure its contribution to health outcomes. But all evaluated the MR training sessions based on any visible changes in motor and cognitive skills for clinical reasoning and adjusted the training accordingly. They all subjectively noticed approvement in health outcomes, but given the context, this is applied to rehabilitation as a whole than just the use of one tool.

Economic Benefit. All participants see possibilities for this novel technique to support the cost-to-benefit by offering MR within group training sessions. With the point of view that the use of this device gives the therapist the ability to train more patients at the same time. This offers more exercise moments for patients without the deployment of additional practitioners. They mention the possibility of additional beneficial aspects of group training in terms of knowledge transfer, increasing motivation for movement, and strengthening the social aspect of rehabilitation. However, they also mentioned a few critical conditions that need to be considered. For example, group participants need to have the same level of physical abilities and goals, availability of a large space with sufficient WIFI connection, purchase of more lenses and live-view screens, planned as usual care, and expansion of game applications that elicit movement accessible for people with disabilities.

DISCUSSION

This mixed methods, exploratory study identified, on a small-scale, overall positive perceptions on usability and usefulness of MR during multidisciplinary SCI/D rehabilitation practice. This, together with the perceived applicability during the pilot period, increases the users' intention to use MR and therefore had a positive influence on the adoption of this technology-based innovation in our multidisciplinary SCI/D rehabilitation practice.

We dealt with limited resources in the areas of time, personnel, and technical support, resulting in a small sample size of participants. Therefore, the findings of this study cannot be generalized and must be interpreted cautiously. However, this reflects a realistic scenario where we encounter often suboptimal conditions and ties with the call from practitioners for more studies to be conducted in settings where constraints are prioritized over optimal conditions, specifically testing the fit of interventions in real-world settings.[30]

Guided by our ambitions, we started this study with a research question focused on many factors and goals at the same time. The literature confirms this well-known pitfall in quality improvement research and implementation programs, which makes it difficult to attribute specific changes to specific interventions or contextual factors.[16] When taking a closer look, we chose areas of focus that best matched our need for the situation and therefore were focused on the first step towards the adoption of a product, namely the attitude of the end users. To capture a holistic picture of this adoption factor, the use of a mixed methods approach was a strong choice, through the ability to converge the qualitative and quantitative data.

We experienced the use of combined approaches, participatory action research with the implementation process model developed by Grol and Wensing, as a strength of this study, since behavioral change processes are inherent in implementation. Lack of knowledge and time to learn are major barriers to the adoption of innovations[14,31] and can therefore affect the PEOU and PU. The use of this combined approach brought our attention to the need to organize and facilitate time to learn to gain knowledge and confidence to translate the use of MR into practice and meaningful treatment and gave us tools to do so. In this way, we consciously executed the process of gaining insight, i.e. understanding what the innovation entails, and discovering and learning together to get to acceptance. This was a crucial step in the process of change among all participants. Since, on the one hand, patient acceptance influences therapists' adoption, because they are trained to be client-centered. On the other hand, the primary driver for patients can be the therapist's recommendation.[32]

Implementing a technology-based innovation requires time and effort to characterize underlying mechanisms to accelerate the movement of the application of technologies into the real world.[33] In this study, the available time constrained us in our ability to address all the identified prerequisites needed to optimize the implementation conditions, mainly of a technical nature, before the start of the pilot period. This had a negative influence on the perceived usability at the beginning of the pilot period. Hence, the necessary technical adjustments, although later than planned, were still conducted during the pilot period. This is reflected in the appreciation of the usability at the end of the pilot period, which is perceived as better when compared with the start. Therefore, we cannot say with certainty whether the improvement in PEOU is the result of the gained user experience over time or from the improvement in the technical conditions.

A recently published systematic review of the potentials and limitations of Microsoft's® Hololens 2 in medical and healthcare context, showed that the lack of guidelines, protocols, and standardization of use are the most critical aspects in describing its feasibility and applicability.[12] To the best of our knowledge, our study is one of the few that addressed precisely this area. Collaboration between all end users resulted in a provisional guideline for working methods in which we assessed the applicability within a multidisciplinary team. To investigate the applicability, it is, in our opinion, important to conduct research within the specific setting and to start on a micro level. Here we did bring to the surface what the end users individually needed to gain knowledge and achieve acceptance. In this study, we used strategies like joint learning, facilitation of knowledge material, and coaching on the job. If there is acceptance, one is more willing to try the application in real-world practice.[16]

With this created provisional guideline we assessed the applicability, based on the user experience of patients and healthcare professionals regarding the feasibility, appropriateness, meaningfulness, and effectiveness of MR. If these components are found positive, it likely has a positive influence on the user attitude. For therapists, the perceived effectiveness might even be the biggest driver for rehabilitation device use.[32] Effectiveness is considered whether the intervention achieves the intended effect which may be a clinical outcome such as measurable changes in improvement of function.[14] Although all participants perceived subjective effectiveness, such as shifting the focus resulting in a reduction in fear of movement or increased motivation resulting in pushing undiscovered boundaries, they all confirmed that they were unable to assess these effects with clinical outcome measures. To be able to show that the use of MR contributes to improvement in physical functions. Lack of this evidence could in some cases negatively affect perceived usefulness, and thus adoption. It is plausible that the perceived meaningfulness, another component of the applicability and related to the perceived usefulness, of MR in this context may have contributed to the positively perceived effectiveness despite the inability to measure clinical outcomes.

Increasing individual training moments can contribute to achieving the intensification of movement training. Despite the experienced usefulness, all patients indicated not to have practiced more often during the pilot period with the availability of MR. Similar findings were found in the work of other researchers.[34] So, although the focus on individual use was not on the scope of this study, enhancing this will affect the PU positively. We found that the patient's willingness to use depends on the interaction between physical and mental characteristics and abilities.[20,35] In this study, the participants see opportunities in offering MR in planned group therapy sessions. With this approach, the load on the patients' willingness is less than with independent practice. An effect of this approach, due to gaining user experience, can be the intensification of movement training through more independent practice. Which may have a positive effect on the perceived usefulness and thus a facilitating influence on the adoption of MR for the targeted patient group.

We experienced the potential of MR to be used in different paramedical disciplines, this could be a factor that can facilitate adoption. This is mainly because our findings show no distinction between the backgrounds of the healthcare practitioners and their MR application in practice. Within the exemplarian phase, all healthcare practitioners showed behavioral and practical changes and spoke about the opportunities and possibilities how integrating MR into their rehabilitation and practice. All healthcare practitioners trained balance, strength, and locomotion with MR, and these are all conditionally needed for the execution of the commonly reported rehabilitation goals, namely mobility and activities of daily living.[13] This challenges us to rather see training towards goals as patient-related and not discipline-related.

Technologies, alone or combined, have the potential to offer a cost-effective way when embedded in rehabilitation practice during the subacute phase to deliver intensive training. Which is essential owing to financial constraints experienced and expected in healthcare.[12,36] By conducting studies like this, even if the conditions are not optimal, this organization showed this willingness to prioritize aligning with the current trends, but also with the predicted future changes like the increasing demand for the application of new technological developments that may affect rehabilitation.

Recommendations for clinical practice

We learned a few lessons from this study that can be useful for other researchers and healthcare practitioners with the ambition to implement innovative rehabilitation technologies into their multidisciplinary rehabilitation practice:

- ◊ Supported by literature and our own experience, we encourage the use of a PAR approach supported by theoretical approaches for behavioral change.[16,30,35] This is to ensure that the study indeed reflects the real-world practice where it is essential to involve stakeholders in meaningful ways to address a broad conceptualization of multidisciplinary adoption to achieve quality improvement by changing practice.
- ◊ PAR is also inherent to communication between the researcher and the researched.

To understand the feelings and actions of the researched, it is indispensable for the researcher to know the reasons for their actions.[22] Therefore, we recommend engaging a researcher who is closely involved with those who are participating in the study. This creates a community with a more common understanding, which in turn will facilitate communication.

- ◊ MR can be used by multiple disciplines as a tool to facilitate patient-specific rehabilitation training during the rehabilitation process. Therefore, we recommend aiming the implementation across the disciplines, this increases the visibility and support among the healthcare practitioners. This is important, since healthcare practitioners are the primary influencers to facilitate rehabilitation device adoption, due to their power of recommendation towards patients and management.[32]
- ◊ Use of learning collaboratively with 'superusers' represents valuable opportunities to provide healthcare practitioners with the tools to increase MR use.[13,38] It would be highly preferred to also involve patients actively during these knowledge-sharing activities since they are end users too. As a result, this will simulate real-world practice in an educational setting.
- ◊ Planned group training could contribute to intensifying movement training, due to increased motivation through collaborative training and it still complies with the preference to have the supervision of a healthcare practitioner to address the goal specificity in training.

CONCLUSION

The intention to use MR during SCI/D rehabilitation depends to a large extent on the users' attitude towards the innovation and the mutual cooperation between the end users. These factors have, therefore, a significant influence on the adoption in clinical practice. Results of this exploratory study, conducted on a small-scale in a multidisciplinary rehabilitation setting, revealed that patients with SCI/D and their healthcare practitioners had an overall positive attitude, i.e. perceived usability and usefulness, towards the use of MR. Assessment of the applicability, following the FAME framework elements, showed that MR with Microsoft's® Hololens 2 is applicable for the targeted group in this specific rehabilitation setting. All aforementioned factors are therefore considered facilitators for adoption and can support subsequent implementation efforts.

At the same time, we gained experience in using a research approach that allowed us to focus on the attitudes and the associated necessary process of behavioral change of our end users. We were able to design materials that support implementation within group collaboration and gained insight into possible forms of applications of MR in this multidisciplinary setting. With the conduction of this study, we provided a start that encourages us to identify and facilitate other important adoption factors that will positively influence the implementation of MR. To aim to ensure sustainable use of MR in our usual care practice to help maintain intensive movement training during the subacute rehabilitation phase.

SUPPLEMENTARY INFORMATION

Acknowledgements

The author would like to thank all the participants for their participation in the study and De Hoogstraat Rehabilitation for the opportunity to conduct this study in their setting. The author also would like to thank Janneke, Eline, Joost, Joke and Iris for their knowledge and support.

Correspondence

J.v.d.lede@dehoogstraat.nl

REFERENCES

1. Van Asbeck FWA, Van Nes IJW. Handboek dwarslaesierevalidatie de basis. 3de druk. Uitgeverij Koninklijke Van Gorcum Publishing; 2016
2. Richard-Denis A, Ehrmann Feldman D, Thompson C, Bourassa-Moreau É, Mac-Thiong JM. Costs and Length of Stay for the Acute Care of Patients with Motor-Complete Spinal Cord Injury Following Cervical Trauma: The Impact of Early Transfer to Specialized Acute SCI Center. Am J Phys Med Rehabil. 2017 Jul;96(7):449-456
3. Scholten EWM, Post MWM, Van Bennekom CAM, Nachtegaal J, Osterthun R, Roels EH, Stolwijk-Swüste JM. Nederlandse Dataset Dwarslaesierevalidatie: Verzamelde gegevens en inhoudelijke herziening. Ned Tijdschrift voor Revalidatiegeneeskunde. 2021; 5:32-34
4. Unger J, Singh H, Mansfield A, Hitzig SL, Lenton E, Musselman KE. The experiences of physical rehabilitation in individuals with spinal cord injuries: a qualitative thematic synthesis. Disabil Rehabil. 2019 Jun;41(12):1367-1383. doi: 10.1080/09638288.2018.1425745. Epub 2018 Jan 15. PMID: 29334811
5. Galea MP. Spinal cord injury and physical activity: preservation of the body. Spinal Cord. 2012 May;50(5):344-51. doi: 10.1038/sc.2011.149. Epub 2011 Dec 13. PMID: 22158253
6. Behrman AL, Ardolino EM, Harkema SJ. Activity-Based Therapy: From Basic Science to Clinical Application for Recovery After Spinal Cord Injury. J Neurol Phys Ther. 2017 Jul;41 Suppl 3(Suppl 3 IV STEP Spec Iss): S39-S45. doi: 10.1097/NPT.0000000000000184. PMID: 28628595; PMCID: PMC5477660
7. Onifer SM, Smith GM, Fouad K. Plasticity after spinal cord injury: relevance to recovery and approaches to facilitate it. Neurotherapeutics. 2011 Apr;8(2):283-93. doi: 10.1007/s13311-011-0034-4. PMID: 21384221; PMCID: PMC3101826
8. Rijksoverheid. Integraal Zorgakkoord: 'Samenwerken aan gezonde zorg' [internet]. September 2022. Available from: http://www.rijksoverheid.nl/documenten/rapporten/2022/09/16/integraal-zorgakkoord-samen-werken-aan-gezonde-zorg
9. De Hoogstraat Revalidatie. Annual rapport [Internet]. 2021 [cited 2022 October 28th]. Available from: http://dehoogstraat.nl/wp-content/uploads/2018/11/Strategische-focus-De-Hoogstraat-2021-2023.pdf
10. Leong SC, Tang YM, Toh FM, Fong KNK. Examining the effectiveness of virtual, augmented, and mixed reality (VAMR) therapy for upper limb recovery and activities of daily living in stroke patients: a systematic review and meta-analysis. J Neuroeng Rehabil. 2022 Aug 24;19(1):93. doi: 10.1186/s12984-022-01071-x. PMID: 36002898; PMCID: PMC9404551
11. Janssen J, Verschuren O, Renger WJ, Ermers J, Ketelaar M, van Ee R. Gamification in Physical Therapy: More Than Using Games. Pediatr Phys Ther. 2017 Jan;29(1):95-99. https://doi: 10.1097/PEP. 0000000000000326
12. Palumbo A. Microsoft HoloLens 2 in Medical and Healthcare Context: State of the Art and Future Prospects. Sensors (Basel). 2022 Oct 11;22(20):7709. doi: 10.3390/s22207709. PMID: 36298059; PMCID: PMC9611914
13. Gauthier C, Walden K, Jervis-Rademeyer H, Musselman KE, Kaiser A, Wolfe DL, Noonan VK, Donkers SJ. Technology used in activity based therapy for individuals living with spinal cord injury across Canada. Spinal Cord Ser Cases. 2023 Jan 16;9(1):1. doi: 10.1038/s41394-022-00558-y. PMID: 36646680; PMCID: PMC9842763
14. Musselman KE, Shah M, Zariffa J. Rehabilitation technologies and interventions for individuals with spinal cord injury: translational potential of current trends. J Neuroeng Rehabil. 2018 May 16;15(1):40. doi: 10.1186/s12984-018-0386-7. PMID: 29769082; PMCID: PMC5956557
15. Davis FD. Perceived usefulness, perceived ease of use, and user acceptance of information technology. MIS Q. 1989;13(3):319
16. Grol R, Wensing M, Grimshaw J. Improving patient care: the implementation of change in health care. 3rd ed. Oxford: Wiley Blackwell; 2020
17. Migchelbrink F. De kern van participatief actieonderzoek. 4de druk. Amsterdam: Uitgeverij SWP Publishing; 2016
18. CommunicatieRijk. Functionele rollen in een netwerk [Internet]. Ministerie van algemene zaken [cited 2022 November 1st] Available from: http://www.communicatierijk.nl/ vakkennis/factor-c/ringen-van-invloed
19. Caluwe de L, Vermaak H. Leren veranderen. Een handboek voor de veranderkundige. 3de druk. Alphen aan den Rijn: Boom uitgevers Amsterdam Publishing; 2019

20. Al-Rawashdeh M, Keikhosrokiani P, Belaton B, Alawida M, Zwiri A. IoT Adoption and Application for Smart Healthcare: A Systematic Review. Sensors (Basel). 2022 Jul 19;22(14):5377. doi: 10.3390/s22145377. PMID: 35891056; PMCID: PMC9316993
21. Grol R, Wensing M. Implementatie: Effectieve verbetering van de patiëntenzorg. 7th ed. Maarssen: Elsevier gezondheidszorg; 2017
22. Coenen H, Khonraad S. Inspirations and aspirations of exemplarian action research. J Community Appl Soc Psychol. 2003;13(6):439–50
23. Marketingmodellen. DESTEP-Analyse [Internet].Marketingmodellen [cited 2022 November 12th] Available from: http://marketingmodellen.com/destep-analyse/
24. Marketing Theorie. 7S Model [Internet]. Marketing Theorie & Artikelo; 2021 [cited 2022 November 11th] Available from https://www.7s-model.nl/strategie/
25. ZonMw. Maak zelf een implementatieplan [Internet]. ZonMw; 2020 [updated 2020 October; cited 2023 March 4th. Available from: https: ://www.zonmw.nl/nl/artikel/maak-zelf-een-implementatieplan
26. Ink. PCDA cyclus [Internet]. [cited 202 May 13th] Available from http://ink.nl/modellen/ink-managementmodel/pdca-imwr/Marketing modellen
27. Brooke, J.B. (1996). SUS: A 'Quick and Dirty' Usability Scale
28. Ensink CJ, Keijsers NLW, Groen BE. Translation and validation of the System Usability Scale to a Dutch version: D-SUS. Disabil Rehabil. 2022 Dec 27:1-6. doi: 10.1080/09638288.2022.2160837. Epub ahead of print. PMID: 36573399
29. Pearson A, Wiechula R, Court A, Lockwood C. The JBI model of evidence-based healthcare. Int J Evid Based Healthc 2005; 3: 207–15
30. Bowen DJ, Kreuter M, Spring B, Cofta-Woerpel L, Linnan L, Weiner D, Bakken S, Kaplan CP, Squiers L, Fabrizio C, Fernandez M. How we design feasibility studies. Am J Prev Med. 2009 May;36(5):452-7. doi: 10.1016/j.amepre.2009.02.002. PMID: 19362699; PMCID: PMC2859314
31. Judy LM, Morrow C, Seo NJ. Development and evaluation of an efficient training program to facilitate the adoption of a novel neurorehabilitation device. J Rehabil Assist Technol Eng. 2023 Feb. 14;10:20556683231158552. doi: 10.1177/20556683231158552. PMID: 36818163; PMCID: PMC9932764
32. Morrow CM, Johnson E, Simpson KN, Seo NJ. Determining Factors that Influence Adoption of New Post-Stroke Sensorimotor Rehabilitation Devices in the USA. IEEE Trans Neural Syst Rehabil Eng. 2021;29:1213-1222. doi: 10.1109/TNSRE.2021.3090571. Epub 2021 Jun 30. PMID: 34143736; PMCID: PMC8249076
33. Morse LR, Field-Fote EC, Contreras-Vidal J, Noble-Haeusslein LJ, Rodreick M, Shields RK, Sofroniew M, Wudlick R, Zanca JM; SCI 2020 Working Group. Meeting Proceedings for SCI 2020: Launching a Decade of Disruption in Spinal Cord Injury Research. J Neurotrauma. 2021 May 1;38(9):1251-1266. doi: 10.1089/neu.2020.7174. Epub 2021 Feb 3. PMID: 33353467
34. Baardman JF, Van Langeveld SA, Janssen J, Stolwijk-Swüste JM. Augmented Rehab – Mixed Reality voor het stimuleren van bewegen en het versterken van voorlichting in de dwarslaesierevalidatie. Ned Tijdschr Revalidatiegeneeskd. Forthcoming December 2022;44(5)
35. Bell A, Grampurohit N, Kains G, Marino RJ. Developing guiding principles for technology-based rehabilitation program by engaging people with motor incomplete tetraplegia. J Neuroeng Rehabil. 2022 Nov 24;19(1):128. doi: 10.1186/s12984-022-01096-2. PMID: 36424612; PMCID: PMC9694851
36. Burridge JH, Hughes AM. Potential for new technologies in clinical practice. Curr Opin Neurol. 2010 Dec;23(6):671-7. doi: 10.1097/WCO.0b013e3283402af5. PMID: 20962639
37. Nederlandse Vereniging van Revalidatieartsen. Behandelkader Dwarslaesie [Internet]. 2019 [cited 2022 October 4th]. Available from: https://revalidatiegeneeskunde.nl/sites/default/files/ attachments /Kwaliteit/ Behandelkaders/behandelkader_dwarslaesie_-_2019-04-12_def.pdf
38. Miech EJ, Rattray NA, Flanagan ME, Damschroder L, Schmid AA, Damush TM. Inside help: An integrative review of champions in healthcare-related implementation. SAGE Open Med. 2018 May 17;6:2050312118773261. doi: 10.1177/2050312118773261. PMID: 29796266; PMCID: PMC5960847

ANNEX 1. User matrix

HOLOLENS GAMES & BEHANDELDOELEN

GEBRUIKERSMATRIX

CATEGORIE

- Lopen
- Staan
- Zitten

		WELK SPEL?				
CATEGORIE	**Behandeldoelen**	Smash Ball	Ruimte Duikelen	Vlinder Vrij	Ballonnen	Doodle
BOVENSTE EXTREMITEIT	ROM vergroten			★	★	
	2 Handigheid	★			★	★
	Reactievermogen	★	★	★		
ROMP	Zitbalans			★	★	
	ROM vergroten	★		★	★	★
OVERIG	Rolstoelvaardigheden	★		★	★	★
	Dubbeltaken	★	★	★	★	
	Beweegangst		★	★	★	
	Ontspanning		★			
	Uithoudingsvermogen (levels met tijd)			★	★	

ANNEX 1 (continued) User matrix

HOLOLENS GAMES & BEHANDELDOELEN

GEBRUIKERSMATRIX

CATEGORIE		WELK SPEL?				
	Lopen					
	Staan					
	Zitten					
	Behandeldoelen	Smash Ball	Ruimte Duikelen	Vlinder Vrij	Ballonnen	Doodle
BOVENSTE EXTREMITEIT	ROM vergroten (reiken)			★	★	
	2 Handigheid	★			★	★
	Reactievermogen	★	★	★		
Onderste Extremiteit	Stap & loopbalans	★		★	★	
	ROM vergroten (bukken, hurken)	★	★			★
	Verplaatsen in de ruimte			★	★	★
OVERIG	Dubbeltaken	★	★	★	★	
	Beweegangst		★	★	★	
	Ontspanning		★			
	Uithoudingsvermogen (levels met tijd)			★	★	