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Research article

Usability of a visual feedback system to assess and improve movement disorders related to neck pain: Perceptions of physical therapists and patients

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A R T I C L E I N F O

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A B S T R A C T

A prototype visual feedback system has been developed to assess and improve movement disorders related to neck pain. The aim of this study was to assess the usability of the prototype in a rehabilitation setting. Twelve physical therapists integrated the device into their regular therapy programs for 24 neck pain patients with movement disorders. Each patient performed three individual therapy sessions with the device under physical therapist supervision. Usability was assessed by the physical therapists and patients using therapy diaries, the System Usability Scale, and focus group or personal interviews.

Based on an overall usability rating of marginally acceptable, the visual feedback system was generally found to be a device with the potential to assess and train neck pain patients but needs improvement.

To become a useful adjunct to regular physical therapy, improvements in the hardware and software, and further system developments are required.

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1. Introduction

Neck pain (NP) is a common and often recurrent disorder worldwide [1], with a 1-year prevalence of 39% and a point prevalence of 13% in the adult population [2]. NP can lead to disability [3] and generate high costs in the health care system and in the economy, due to work absenteeism and presenteeism [4]. After low back pain, NP is one of the main musculoskeletal disorders with a 54% increase in the 'years lived with disability' between 1990 and 2013 [5]. Current clinical guidelines recommend active rehabilitation, including exercises, to restore optimal function [6,7]. Tailored exercise programmes that address individual functional deficits are regarded as superior to general physical activity [8] and to general neck exercises [9] in reducing neck pain and disability. Therefore, a precise assessment of functional deficits in NP patients should be the basis for any individually-targeted treatment approach in physical therapy [10].

Functional impairments frequently seen in NP patients are reduced range of motion [11,12], neuromuscular disturbances [12], altered joint position sense [13,14], and alterations in sensorimotor control [15–17]. A successful rehabilitation to improve these functional impairments and to recover physical function requires the appropriate combination and progression of exercises [1]. Current modalities of rehabilitation include assessment and both supervised and unsupervised exercises, but advances in technology may open new horizons in this field. Virtual reality, augmented reality, gamification, and telerehabilitation are appealing for the rehabilitation of neck pain patients [18,19]. The concept of gamification is based on the application of "game design elements in a non-game context" to motivate participation [20]. Beneficial effects have been reported in several fields of disability (e.g., idiopathic scoliosis and stroke rehabilitation) [21]. These technologies offer the prospect of an increase in home exercise times, as well as in the number of patients who can be treated simultaneously [22,23]. Another positive aspect of these rehabilitative modes is the visual feedback received by the patient and health care provider, which increases compliance to treatment [24]. Studies have demonstrated that remote virtual rehabilitation enhances patient motivation and improves adherence to therapy [25]. If such approaches were to be combined with precise measurement of outcomes, such as movement quantification, the personalization of exercises targeted at the individual patient's needs would become possible.

Despite this, there has been little research and innovation on gamification approaches to neck pain rehabilitation, although they are gaining in importance to increase motivation and adherence and may provide visual and acoustic feedback modalities to improve learning of movement and motor tasks [26]. To overcome this deficiency, a prototype of a visual feedback (VF) device for neck pain therapy has been developed. The VF device is designed to assess movement dysfunctions related to neck pain and to improve these disorders through specifically targeted exercises. The development of the VF device followed a User Centered Design (UCD) approach [27], involving potential users from the early stages of technological development to ensure that its structure, content, and design are driven by the needs, expectations, and understanding of the users. The UCD approach helps developers to identify and fulfil user needs and requirements at the prototyping stage of a technology [28].

The aim of this study was to test the first prototype of a VF device with both physical therapists (PT) and neck pain patient users to assess their needs and requirements. The results of the study will form the basis for the development of future prototype generations.

2. Methods

2.1. Participants

Twelve PTs from two outpatient rehabilitation clinics and two PT practices participated in the study. The PTs recruited 24 patients with neck pain and associated movement disorders which were confirmed following the site specific standard operating procedures and guidelines. Each PT treated two patients who were permanently assigned to the PT. A movement disorder was defined as either 'reduced active control of movement' [29] or 'reduced range of motion of the neck' compared to reference values [30,31]. Additional inclusion criteria were age ≥18 years, neck pain of traumatic or idiopathic origin, and/or headache originating from the neck. Exclusion criteria were specific neck pain/headache, and neck pain radiating beyond the shoulder region.

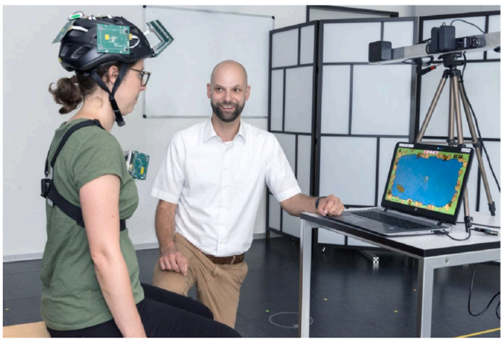

Fig. 1. The VF device visualizes the patient's movement on the screen. Simultaneously, the movement is analyzed by a head unit mounted on a helmet, a sternum unit, and two HTC wife laser emitting diodes.

2.2. Device

The VF device is comprised of a tracking system and a computerized training system based on visual feedback (Fig. 1).

The tracking system has been described in detail in a previous study and, therefore, is summarized only briefly here [32,33]. Its validity was confirmed, while its reliability was task-specific but independent of the device [33].The tracking principle follows the virtual-reality system Steam®VR-Tracking. This consists of two High Tech Computer Corporation (HTC) laser-emitting lighthouses combined with two trackers, which are connected to a laptop PC via Bluetooth low energy at a rate of 30Hz, for tracking head and trunk motion. For tracking we adopted the technology used in the HTC-Vive virtual reality glasses, which consists essentially of HTC's Gen1 laser emitting base-stations and the headset to be tracked. Instead of a headset we used our own lightweight development of trackers that were mounted on the head unit respectively trunk unit. The head and trunk units combined weight a total of 1.05 kg/2,31 lbs (head unit 0.7 kg/1.54 lbs). Neck movements are defined as the movement between the head (*F*) and trunk (*T*) and expressed as the relative 4x4 pose matrix representing rotation and translation in space

$$T_T^F = T_R^F \left(T_R^T\right)^{-1},$$

with T_R^F being the 4x4 transformation matrix from the reference (*R)* to the forehead (*F)* coordinate system, and T_R^T being the transformation matrix from the reference (*R*) to the trunk (*T*) coordinate system. The pose T_T^F forms the basis for the 3-D assessments and exercises of the computerized training system, programmed in Unity3D, which incorporates gamification aspects for:

- **Assessment** of cervical range of motion (RoM) and joint position error (JPE) for neck pain patients with neuromuscular coordination problems, with/without dizziness, or RoM disabilities. JPE assessment tests a patient's ability to move back to a neutral neck position after making a specific head/neck movement) [13,14,34,35].
- **Improvement** of cervical RoM, JPE and coordination in neck pain patients with neuromuscular coordination problems, with/without dizziness, or range of motion disabilities
- **Improvement** in cervical movement control/active stabilization of the cervical spine in neck pain patients

These aims resulted in three exercise categories: a) Active Control of Movement exercises; b) JPE exercises; and c) Active Stabilization exercises. Thus, the VF system supports the following therapy goals of the International Classification of Health Intervention (ICHI) - Interventions on Body Systems and Functions – 10 Interventions on the Musculoskeletal System – Movement (ICHI 1-10-MV) domain [36]:

- MVD.AA.ZZ - Assessment control of voluntary movement
- MVD.PG.ZZ - Assisting and leading exercise for control of voluntary movement functions
- MVD.PH.ZZ - Training motor control

These goals were selected following the applicable international guidelines and considering the importance of these functions for ergonomic postures and movements [6,37,38].

During the assessments and exercises, the patients sat upright with their head starting in neutral position in front of the laptop, similar to an ergonomic work place, or stood upright with their head starting in neutral position with the laptops' height adjusted accordingly. The PTs chose the appropriate position together with the patients.

2.3. Procedure

The PTs received 3 h of instruction from the investigators prior to the start of the study. They then integrated the VF system into the rehabilitation setting by adding three additional therapy sessions of 30 min duration to the regular sessions of their physical therapy programs. Supervised by the PT, patients underwent assessment and therapy using the VF system. The content of each 30-min therapy session was decided by the physical therapist, according to the patient's overall therapy goals and condition. The PT selected the number, type, mode, order, speed, and duration of the assessments and exercises in each session. The same PT supervised all sessions for each patient. The PT assisted the patient in the donning and doffing of the VF system and in setting up the hardware and software.

2.3.1. Exercise games

A set of exercise games were developed based on Valedo®Motion (Hocoma, Volketswil, CH) and executed on a standard notebook in a normally illuminated room (Fig. 1). The software allowed the therapists to assemble individual training programs from the set of installed exercises, i.e. computer games. The exercises were developed with the PT's of the project team for the assessments and interventions described above. While many exercises were simple visualizations of the subject's current posture and some targets on a white screen, the three most frequently used, and more complex exercises are described in detail in appendix 2.

2.4. Data collection

All data collection instruments are presented in the Appendix.

Participants were selected according a purposive sampling method. Participants were selected based on the purpose of the study with the expectation that each participant will provide unique and rich information of value to the study. Because of this, members of the accessible sample are not interchangeable, and the sample size is determined by data saturation and not statistical power analysis [39].

Physical therapists: A mixed-method approach was used to explore the usability of the VF system from the PT's perspective, using a diary, the System Usability Scale (SUS) [40], and a focus group interview. The PT completed a diary for each patient before the first treatment session, detailing the sociodemographic data of the patient, the patient's symptoms (4 items), therapy goals (2 items) and the therapist's expectations (3 items). Following each therapy session, the PT gave feedback to questions on the usage of the VF device for the assessments/exercises. After the last session, the general impressions of the PT were captured (11 items) and the PT completed the SUS questionnaire. A score of 75 points or higher on the SUS indicates 'good' usability of a device [41]. Finally, a focus group interview was conducted to learn more about the personal experiences of each PT with the VF system. According to the research question and the aim of the study the research team developed the main categories for the guideline. The guideline for the focus group discussion covered the topics of "current physical therapy practice in neck pain therapy", "general impression", "usefulness", "dents", "ease of use of hardware and games", "assessments, exercises", "feedback modes", "collaboration with physical therapist", "advancement", and "concluding remarks".

Neck pain patients: A mixed-method approach was also used to explore the usability of the VF system from the patient's perspective, using a diary, the SUS questionnaire, and a personal interview. At baseline, the diary recorded information on the patient's neck pain (3 items), their attitude towards gaming (3 items), their expectations (1 item), and a 10-point Numeric Rating Scale (NRS) measuring mean pain intensity over the last seven days, ranging from 0 (no pain) to 10 (worst pain imaginable) [42]. Following each session, feedback from the patient focused on the usage of the VF device for assessments/exercises: dents or exacerbation of symptoms experienced (1 item), motivation (1 item), and exertion (1 item). The latter was assessed using the NRS scale. After the last session, the feedback concentrated on the topics of "general impression" (one item) and "feedback on hardware, software, and system as a whole" (11 items). The patients also completed the SUS questionnaire and were interviewed personally. The interview covered the topics of "general remarks", "previous experiences with neck pain therapy", "general impression", "expectations", "ease of use of hardware and games", "feedback modes", "collaboration with physical therapist", "advancement", and "concluding remarks".

Table 1
Participants' characteristics.

Characteristics	M ± SD (Range); n (%)
Patients	N = 24
Age (years)	49.3 ± 19.2 (18–88)
Gender	
Female	21 (87.5%)
male	3 (12.5%)
Symptoms	
Neck pain (traumatic/idiopathic)	20 (83%)
Headache	13 (54%)
Movement control disorders	11 (46%)
Constrained range of motion	8 (33%)
Extended range of motion	3 (13%)
Pain intensity (Scale 1–10)	5.0 ± 2.5 (1–10)
Impact of neck pain on daily life	
Constraints in activities of daily living	17 (71 %)
Constraints in job activities	10 (42 %)
Constraints in leisure activities	20 83 %)
Use of ICT and games	
Use of smartphones, tablets, or PCs: several times a day	18 (75%)
Regular use of video or computer games	5 (21%)
Number of completed therapy sessions with VF system	
3 Sessions	19 (78%)
2 Sessions	3 (13%)
1 Session	2 (8%)
Therapists	***N = 12***
Gender	
Female	8 (67%)
male	4 (33%)
Work environment	
University hospital	4 (33%)
Cantonal hospital	4 (33%)
Outpatient sports clinic	2 (17%)
Outpatient physiotherapy practice	2 (17%)
Work experience in the specific setting (years)	7.1 ± 0.6 (0.5–18)
Workload (%)	77.3 ± 25.7 (20–100)

Notes Table 1: M = arithmetic mean, SD = Standard Deviation.

2.5. Data analyses

Quantitative data from diaries and questionnaires (SUS, NRS) were analyzed descriptively using IBM SPSS Statistics version 26. Response frequencies, means, standard deviations, ranges and interquartile ranges were calculated.

The focus group and patient interviews were analyzed for emerging themes using the content structuring analysis [43,44]. The usability of medical devices has multiple layers and focuses on effectiveness, efficiency, satisfaction and safety [45]. To obtain a multi-layered understanding of the VF system's usability, the concept of triangulation was chosen [46,47]. Triangulation helps to consider and record diversity and contradictions of a research object. Different methodological procedures and different data are related (between-method) to each other to discover emerging themes. This complementary mixed methods approach enhances the strengths and minimizes the weaknesses of monomethod approaches [48]. Feedback from patients and PTs were weighted equally. Quantitative and qualitative data were integrated according to the concept of triangulation [46,47].

3. Results

3.1. Participants

Table 1 illustrates the characteristics of the PTs and patients (Table 1). The PTs had an average work experience of 7 years in their current work environment and a mean workload of 77%. Most patients suffered from traumatic or idiopathic neck pain (83%) of middle intensity (5 points on the NRS).

3.2. Emerging themes

During the triangulation process, the following main themes emerged: 1) Overall usability; 2) Usefulness (understood as the system's usefulness, based on ratings by physical therapists and patients); 3) Efficiency (defined as total costs to achieve this goal); 4) Satisfaction (understood as the sentiment prompted in the operator by the system (pleasure, feelings of disturbance, or assistance), and 5) Suggestions for improvement.

3.2.1. Overall usability

The mean SUS score rated by the patients was 60 (range: 15–83; SD = 16.9). The mean SUS score rated by the PTs was slightly lower at 55 points (range: 30–83; SD = 15.1), which corresponds to an adjective rating of marginally acceptable [49]. Lowest SUS values were given for the items "I thought there was too much inconsistency in this system" (78 % of patients and 82 % of therapists at least partially agreed with this statement), and "I think I would like to use this system frequently" (54.6 % of therapists disagreed or rather disagreed with this statement).

3.2.2. Usefulness

Effectiveness was not measured objectively but reflected the subjective views of both patient and PT participants. Participant ratings of effectiveness were provided separately for the assessments, games, and overall training.

3.2.2.1. Assessments. The PT chose one, or several, of the seven possible assessments for each therapy session and afterwards rated its usefulness in achieving the therapy goal. Fig. 2 illustrates the frequency of usage of each assessment and its usefulness ratings. The

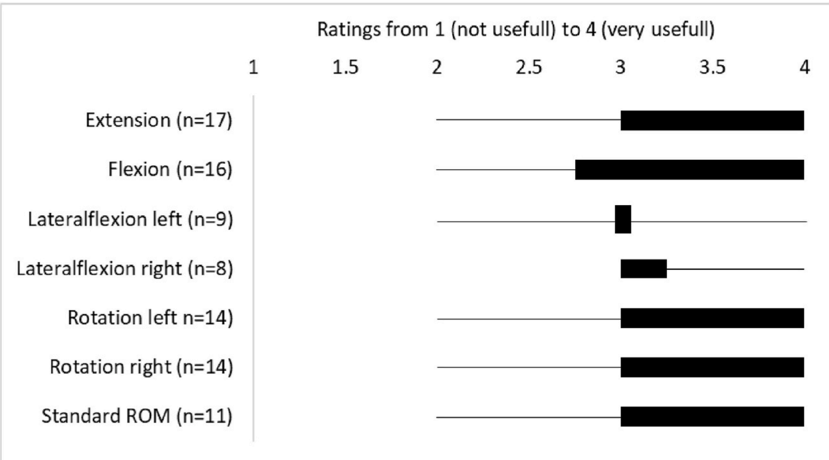

Fig. 2. Therapist ratings of the usefulness of the assessments in achieving therapy aims. Thin lines indicate the range of participant ratings; Thick bars represent the range of the first to third quartile.

usefulness of all assessments was rated high, with interquartile ranges between 2.8 and 4. Arithmetic means were in the range of 3.1–3.5, with the highest mean value for Standard ROM.

3.2.2.2. Forms of exercise. The PTs trained all patients (n = 24) at least once using Active Control of Movement exercises. Additionally, 23 patients were trained by performing JPE exercises, and 16 (at least once) through Active Stabilization exercises. PT ratings of the usefulness of these exercises are depicted in Figs. 3–5, respectively.

3.2.2.3. Training. Patients assessed training exertion using the NRS, and reported a mean exertion of 5.6 (SD = 2.5) in the first training session, of 4.9 (SD = 2.6) in the second, and of 5.1 (SD = 2.7) in the third training session. Most patients and the PTs rather, or fully, agreed that patients had trained intensively (65%), and that the VF system had supported them in performing their exercises adequately (61%).

Patients and PTs considered the training with the VF system useful for the following reasons: 1) The system provides feedback on the quality of the patient's positions and movements and, therefore, facilitates proprioception and awareness of personal limits; 2) The system provides feedback on the patient's performance a) in relation to a healthy population, and b) in a longitudinal course; 3) It is conceivable that a home training will be developed that patients regard as a useful complement to therapy; 4) Gamification factors enhance motivation to exercise.

3.2.3. Efficiency

Aspects related to the system's efficiency were addressed in the following domains: *Time required to prepare the system for training*; *System transparency regarding data assessment, analysis, and feedback*; *Intuitive usability*; *Task difficulty*; *Technical problems;* and *Equipment*.

3.2.3.1. Time to prepare the system for training. The PT required 16 min to prepare the system for training with a specific patient for the first session, 8 min for the second, and 6 min for the third session. In those therapy settings where the infrastructure for the VF system could be permanently installed, preparation for training took a mean time of 4.7 min. However, 54% of PTs (rather) considered the preparation time to be 'not reasonable'.

3.2.3.2. Transparency of data assessment, analysis, and feedback. The assessments and games were generally seen as useful in achieving the therapy goals. However, for some PTs, the therapeutic aims of the games were to a certain extent unclear. They were also uncertain of the quality of data assessment and analysis, and about how to interpret the feedback from the system. Patients did not question the quality of data assessment and feedback, but they did reflect on whether training with the VF system would deliver long-term effects.

3.2.3.3. Intuitive usability. Not only was the preparation of the system time-consuming, but for some PTs it was also problematic: 17% (rather) did not agree that the starting procedure of assessments and games in the system had been easy. In the focus groups, the PTs remarked that the software still lacked intuitive usability. For example, creating a report for a specific patient had been difficult. Additionally, patients mentioned in their interviews that training with the VF system might be strenuous for those patients who were "not accustomed to games or PCs".

3.2.3.4. Task difficulty. The feedback from patients relating to the difficulty of the games was heterogeneous: the tasks were easy for some patients, while they were (too) difficult for others. One patient reported that the VF system games did not feel as "appropriate" as conservative exercises. Concentration and focus on a screen transpired to be difficult for patients with neck pain-related headache. Some patients criticized that the games required all their concentration, with the neck training itself becoming of secondary

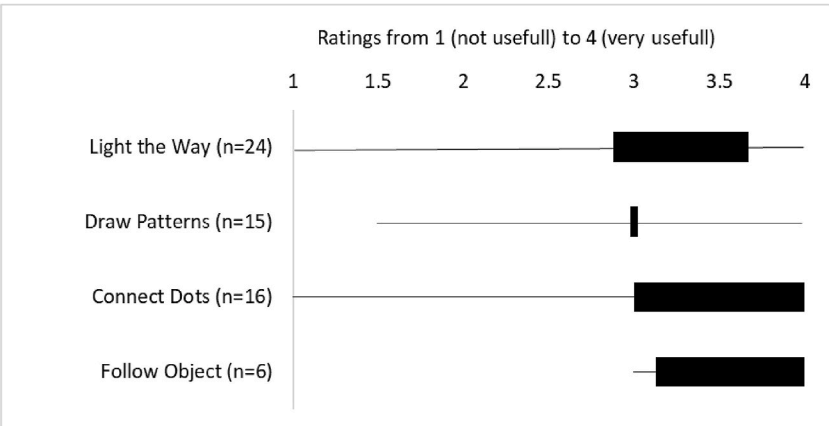

Fig. 3. Therapist ratings of the usefulness of Active Control of Movement exercises in achieving therapy aims. Thin lines indicate the range of participant ratings; Thick bars represent the range of the first to third quartile.

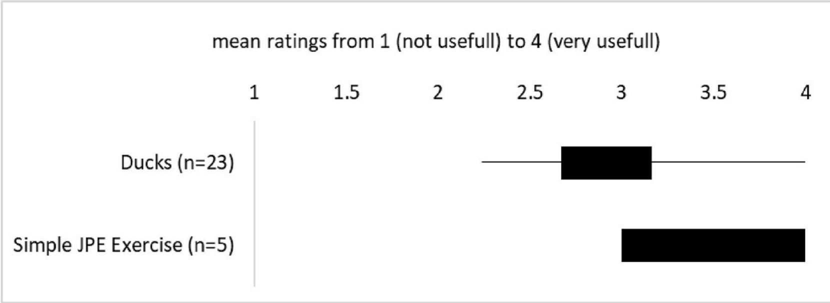

Fig. 4. Therapist ratings of the usefulness of JPE exercises in achieving therapy aims. Thin lines indicate the range of participant ratings; Thick bars represent the range of the first to third quartile.

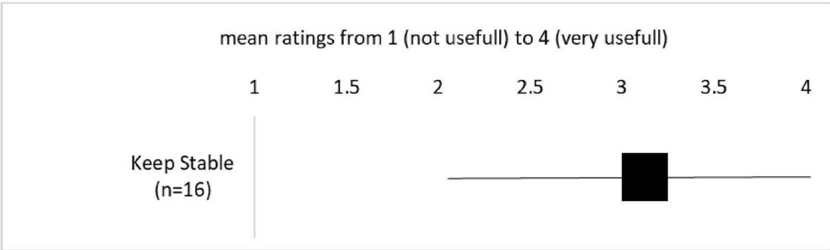

Fig. 5. Therapist ratings of the usefulness of Active Stabilization exercises to achieve therapy aims. Thin lines indicate the range of participant ratings; Thick bars represent the range of the first to third quartile.

consideration. The therapeutic activity focused on the screen, concentrating on the activation of isolated neck muscles, meant that other musculoskeletal parts were neglected in the meanwhile.

3.2.3.5. Technical problems. The following problems with hardware and software were reported:

- Freezing of the display
- Loss of signal contact
- Jumps in visualized movement
- Positioning of the sternum strap was complicated with higher bust sizes

3.2.3.6. Equipment. The VF system equipment required storage space and space was needed to train. The PTs judged this to be a barrier, since space in any therapeutic setting is limited. This aspect was also highlighted by the patients when they pondered about

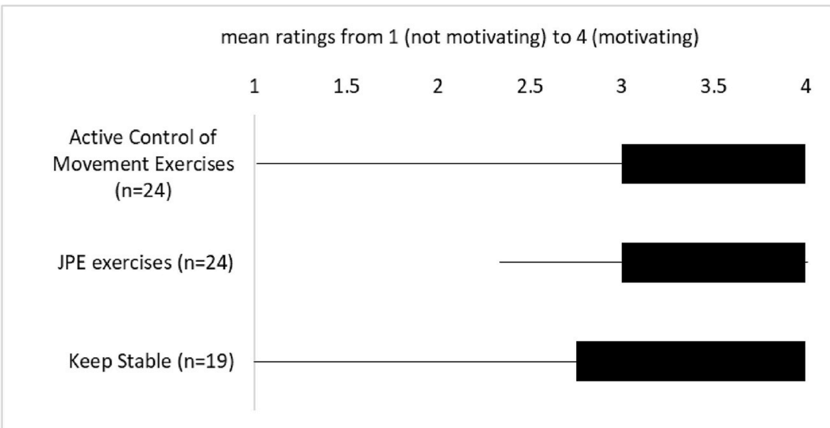

Fig. 6. Patient ratings of motivational effects of VF system games;,Thin lines indicate the range of participants ratings; Thick bars represent the range of the first to third quartile.

training at home or while traveling. In contrast, conservative exercises can be practised anywhere and require no preparation.

3.2.4. Satisfaction

The following dimensions represent the sentiments prompted by the system in patients and PTs: *Joy and motivation*; *Liking of the design of the games*; *Feeling* supported *by the feedback provided*; and *Perception of barriers*.

3.2.4.1. Joy and motivation. Nearly all patients (95%) (rather) agreed that gaming was fun. When asked immediately after, "How much did you enjoy the training?", they gave high values for enjoyment (arithmetic mean (M) = 7.8 (SD = 2.2) on a scale from 1 to 10). They furthermore stated that the games motivated them to train (see Fig. 6). This statement applied mainly to *JPE exercises* (M = 3.6, SD = 0.5) and *Active Control of Movement exercises* (M = 3.4, SD = 0.7). For *Active Stabilization exercises*, agreement values for motivation from patients showed more variation (M = 3.1, SD = 1.0).

In the interviews, patients acknowledged the fun factor of playing games and the resulting motivation to exercise. Concentration on a game allowed patients to exercise while forgetting the cause of their pain, or even the pain itself. Some of them appreciated that exercising with the games facilitated movements that they were not usually able to perform in everyday activities because of the associated pain. However, patients raised concerns regarding the long-term motivational effect of the games. They also favoured a choice of multiple methods to train their neck, considering the VF system as a complement to traditional neck exercises, rather than a substitute.

From the perspective of the PTs, most patients had been (rather) motivated (91%) to train with the VF system. They considered that systems, such as the VF system, could enhance motivation for physical activity and elicit a more active lifestyle in chronic pain patients. PTs valued the gaming aspect of the VF system. An important consideration for PTs was that the system was able to measure the effects of neck therapy.

3.2.4.2. Liking the design of the games. Most patients rated the design of the games as attractive defined as visual appealing and fun (see Fig. 7). Arithmetic mean ratings were highest for the JPE exercises (M = 3.8, SD = 0.4) and the *Active Control of Movement exercises* (M = 3.6, SD = 0.7), and slightly lower for the *Active Stabilization exercises* (M = 3.1, SD = 1.0) (see Fig. 6).

3.2.4.3. Feeling supported by the feedback provided. Patients felt supported by the availability of numerical feedback on their movements. The feedback helped them to recognize malposition and to correct posture and movements when necessary.

3.2.4.4. Perception of barriers. Some factors were revealed in the patient interviews and in the PT focus groups that threaten to overshadow the positive effects of the system:

- Unreliable functioning of the sensors
- Time-consuming preparation of hardware and software, incl. calibration: this time could be invested in the patient's therapy (opportunity cost)
- Time-consuming assessments, reducing the time available for gaming
- Loss of connections while calibrating, leading to measurement errors
- Uncomfortable positioning of the sternum strap
- Discomfort experienced from the helmet (weight, fit, hygiene)
- Quality of the system's feedback

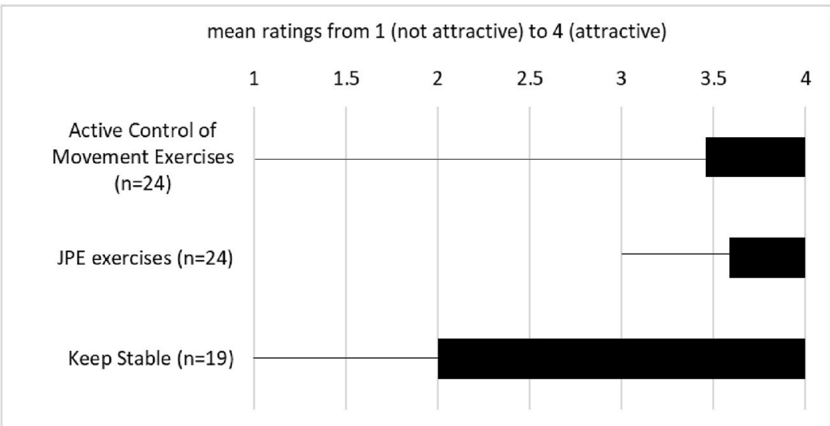

Fig. 7. Patient ratings of the attractiveness of VF system games;,Thin lines indicate the range of participants ratings; Thick bars represent the range of the first to third quartile.

- System did not force patients to move correctly: therapists observed patients successfully playing the games despite an inadequate posture

3.3. Suggestions for improvement

Both patients and physical therapists made suggestions to improve the VF training system. These can be divided into two domains: *Hardware and software requirements*, and *Requirements to provide a useful counterpart to regular physiotherapy*. Illustrations can be found in Table 2.

4. Discussion

This study used a UCD approach to assess the usability of a prototype VF system for the rehabilitation of neck pain patients. The VF system advances the rapidly evolving in state of the art in various levels, particularly regarding practical points of assessments and exercise delivery [50]. The VF system integrates a streamlined assessment module that provides for clinically relevant and functional assessments without requiring the patient to change positions between assessments and or requiring much space [50–52]. The low requirements for the premises allow for a functional, quiet and professional therapy environment and almost barrier-free interaction between therapist and patient [53]. Since no further exercise materials are required, the complexity of the exercises remains low which is beneficial for single-use sessions without a therapist [50]. These could also make the system suitable for telerehabilitation setting in the future [54]. Motivation is important [55], and the VF system can provide for motivation during therapy sessions. The VF system was generally found to have potential to assess and train neck pain patients, but with some limitations (discussed below). To become a useful adjunct to regular physical therapy, improvements in the hardware and software and further system development are required.

4.1. Hardware and software requirements

The hardware and software were evaluated as 'insufficiently useable'. This could have been due to the following factors: Deficiencies in the fitting of electronics; Time required for setup; Restrictions to the exercise setup caused, for example, by the selection of electronics and laptop computer, the software architecture and interface.

The deficiencies in the fitting of electronics could be improved by integrating them into a textile, thus replacing the helmet and sternum units. This might lead to improved efficiency of the system and increased satisfaction on the PT's and patient's side, by reducing the technical problems and improving the equipment. However, the electronics would need to be encapsulated and integrated without impairment of their functionality and operability. Consideration must also be given to the important factors of protection and washability and various parameters must be considered and optimized to obtain the best packaging and textile solution [56,57]. The tracking technology currently used restricts the exercise setup to situations where the patient is within the field of view of the cameras. In this context, a large number of studies have investigated systems consisting of Inertial Measurement Units (IMU) [58]. The attractiveness of this approach lies in its simplicity, low price, small form, and weight. Despite these research efforts, IMU-based pose tracking systems are severely impaired by drift errors, which appear when acceleration and angular velocity signals are integrated to obtain positions and orientation values [59]. While orientation drift can be eliminated through sensing the earth's magnetic field, position drift remains an unresolved issue. An alternative is a well-known measurement principle, known as alternating magnetic-field tracking, which results in pose tracking systems with excellent properties. These should be further investigated for usage in VF devices for neck pain rehabilitation [60]. Other improvements, which would be faster to implement, are use of a larger screen, replacement of the laptop with a touch screen pad, the front-end interface, and use of a faster connection between the tracking electronics and the computer. This might improve the efficiency of the system by increasing the systems' intuitiveness. One possible improvement for the front-end interface and to shorten the setup time might be to include prefabricated exercise programs specific to each therapy goal, possibly leading to decreased setup time for the system and improved intuitive usability. This could be achieved through an agile development process, whereby each aspect is tested, adapted and retested in an iterative process [61]. Given the poorer feedback these

Table 2
Suggestions for improvement from patients and therapists.

Hardware and software requirements	Requirements to provide a useful counterpart to regular physical therapy
- The system must work without any problems - It must be installed quickly - Software and hardware should be handled more easily: e.g., an overview of the software's content could facilitate understanding and navigation - User comfort improvement through lighter weight equipment	- More games, richer in variety to foster pleasurable experiences and, therefore, training motivation - More variety in movements: exercises in standing position or in squats - More feedback: information on training, progress, comparable data and potential to improve - Intensify gamification character: acoustic signals, feedback on levels, scores, percentiles compared to other patients - Final reports (played games, performance, scores), easily created, that therapists may provide to patients - Provision of longitudinal data of patients' performance

improvements should be prioritised over improvements of the games which are discussed below.

4.2. Requirements to provide a useful counterpart to regular physical therapy

Games that reflect the needs of the users more accurately than the current prototype should be included, and which allow a greater variety, difficulty, and progression, thus increasing satisfaction by improving joy and motivation, design of the games and the feedback provided. When defining the corresponding user personas, aspects other than the various movement disorders already incorporated should be considered [62]. These aspects should include the full range of biopsychosocial variables, such as the user's age, tech-savviness, and their individual preferences regarding the degree of visual feedback and seriousness in games. These measures might improve the perceived usefulness of the system, efficiency through more varied task difficulty, and satisfaction by increasing joy and motivation and improving the feedback provided. The improvements in hardware and software could facilitate more varied training sessions. The patients would not be restricted to sitting in front of a screen during training. This would make it suitable for a wider range of pain behaviors. Further exercises could be integrated, ranging from standing to functional exercises, and the incorporation of shoulder, upper extremities and trunk exercises would be facilitated [10,63]. Other feedback modalities, such as acoustic feedback, would make the user more independent of the screen and increase the choice of exercise positions. This could be of major importance, since sitting in front of a computer is frequently associated with a protracted forward head posture, which is in turn associated with headaches, such as migraines, tension-type, and cervicogenic headache, neck pain, and even shoulder problems [64–67]. Further aspects that could increase motivation are the introduction of a ranking list and point system for different exercises, development curves, and anonymized comparisons with similar patients. These aspects should also be tested in an agile development process, with each alteration being analyzed, the deficits defined, and the design adapted to improve the VF device. In this manner, new requirements can be identified during the process [61].

4.3. Outlook

The use of UCD has shown that the involvement of potential users in the early design and testing of a technology is useful in increasing its functionality and usability and in promoting the intended health outcomes [68]. Identified limitations need to be improved through agile development processes and more intensive technological development of the hardware. Future research on this novel therapy approach should also address the issue of which subgroup(s) of patients with neck pain would benefit most from VF exercises. The subgrouping could be based upon functional outcomes, such as the Neck Disability Index [69,70], or on propositions made by recognized clinical guidelines [6,71,72] and experts in the field [10,63]. This approach would assist in determining the design of therapy programs for movement disorders associated with neck pain. The aim of the therapy programs are to meet the patient's needs based on his level of impairment and to maximize the benefits to the individual patient, both in terms of their functional activities and pain levels. It would enable the rehabilitation of a wider spectrum of patients with specific neck pain disorders [63]. The VF device has the potential to become an appropriate training tool for neck pain patients.

5. Conclusions

The therapy approach using the VF system is promising and could enhance the assessment and exercise opportunities in neck pain rehabilitation. With further development, it has the potential to be appropriate for the treatment of movement disorders related to neck pain. Improvements to hardware and software are necessary for it to be capable of functioning as a counterpart to regular physical therapy treatment.

Ethical approval and consent to participate

All participants were informed orally and in writing about the purpose and procedures of the study and signed a written informed consent before inclusion. The ethics committee of the Canton Zurich, Switzerland, verified the study juristically (Req-2017-00709). All participants gave their written informed consent for their data to be published (2017-00709).

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Data availability statement

All data are available from the corresponding author upon a reasonable request.

CRediT authorship contribution statement

I. Nast: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **M. Scheermesser:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – review & editing. **M.J. Ernst:** Conceptualization, Methodology, Writing – review & editing. **B. Sommer:** Conceptualization, Methodology, Writing –

review & editing. **P. Schmid:** Conceptualization, Methodology, Writing – review & editing. **M. Weisenhorn:** Conceptualization, Methodology, Writing – review & editing. **Bärtschi E:** Conceptualization, Methodology, Writing – review & editing, Data curation, Investigation. **D. Gomez:** Conceptualization, Data curation, Investigation, Methodology, Writing – review & editing. **P. Iten:** Conceptualization, Data curation, Investigation, Methodology, Writing – review & editing. **A. von Wartburg:** Conceptualization, Software, Writing – review & editing. **W.O. Frey:** Conceptualization, Investigation, Writing – review & editing. **L. Lünenburger:** Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Writing – review & editing. **C. M. Bauer:** Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Validation, Writing – original draft.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: All authors report financial support was provided by Innosuisse Swiss Innovation Agency. Lars Luenenburger and Angela von Wartburg report a relationship with Hocoma AG that includes: employment. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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