Exploring feedback requirements for the design of technology enhanced vibrotactile feedback strategy for home-based physiotherapy exercises: An Interview Study Among Physiotherapists

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Abstract

Background: Effective treatment in physiotherapy requires hands-on therapy with therapists as well as hands-off treatment like home exercises. To compensate the lack of feedback for home exercising, various technical approaches are studied and developed. Well studied feedback strategies for this use case are missing, especially for tactile feedback.

Objective: This paper combines principles of user-centered design and psychology of learning and aims to derive requirements for designing a vibrotactile feedback strategy for a wearable device for physiotherapy home exercises.

Methods: The feedback behavior of nine physical therapists was observed in a simulated training session and recommendations for a technical feedback system were observed and collected in a guided interview. Data were analyzed along the categories of a deductively and inductively created category system. Frequency distributions of the quantified observation data were created, and qualitative interview data were evaluated using content structuring content analysis.

Results: The present work highlights that reduced feedback frequency, differentiated feedback content, multimodal feedback, and trunk-proximal tactile feedback were recommended by physical therapists for a technical feedback system for the correct performance of physiotherapeutic home exercises in the treatment of unspecific low back pain

Conclusions: This paper offers approaches for the design of a vibrotactile feedback strategy. These approaches should be tested in hypotheses driven research. Further patient studies should be conducted.

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Exploring feedback requirements for the design of technology enhanced vibrotactile feedback strategy for home-based physiotherapy exercises: An Interview Study Among Physiotherapists

Abstract

Background

Physiotherapy treatments often combine hands-on therapist-led exercises as well as hands-off home-based exercises, whereby patients exercise on their own. A critical challenge in home-based exercises is the provision of feedback to patients to guide them in their rehabilitation movements. Different strategies are under scrutiny to overcome this issue, and a starting point for developing effective and implementable strategies is to gather feedback requirements from the end-users.

Objective

This study combines principles of user-centered design and psychology of learning and aims to derive requirements for designing a vibrotactile feedback strategy for a wearable device for physiotherapy home exercises.

Methods

The feedback behavior of nine physical therapists was observed in a simulated training session and their recommendations for a technical feedback system were collected in a guided interview. Data were analyzed using categories of a deductively and inductively created category system. Frequency distributions of the quantified observation data were created, and qualitative interview data were evaluated using content structuring content analysis.

Results

The present work highlights that reduced feedback frequency, differentiated feedback content, multimodal feedback, and trunk-proximal tactile feedback were recommended by physical therapists for a technical feedback system for the correct performance of physiotherapeutic home exercises.

Conclusion

This study offers insights for the design of a vibrotactile feedback strategy. These approaches should be tested in hypotheses driven research. Further patient studies should be conducted.

Introduction

Background

Feedback given to patients plays a relevant role in physiotherapy [1] and can positively influence therapy goals [2]. Physiotherapists can provide hands-on feedback to patients during treatment.

This external feedback is missing for patients in a hands-off context when they perform exercises at home. The treatment with home exercises has been increasing in recent years. The increase is due on the one hand, to the effectiveness of active methods instead of passive treatment approaches, and on the other hand, to the shortage of health care workers [3]. Standard technologies are apps or other devices providing visual or auditory feedback [4–11], some of them using gamification approaches [12,13]. Recent technological developments include tactile Internet Technologies (TaHiL). They manipulate and control virtual or real objects with almost no latency, i.e., with minimal delay in data transmission. The possibility of providing real-time tactile feedback is given. Technology-enhanced tactile feedback can have positive effects on the performance and learning of motor skills [14–19] and is applicated in rehabilitation [20–23].

This study is part of developing and researching a haptic physiotherapy assistant. This corresponds to a wearable, a body-worn cyber-physical system that enables a new type of multimodal human-machine interaction using vibrotactile feedback. The resulting vibrotactile feedback strategy will be included in an AI-supported expert system, which is worn directly on the skin. Integrated IMU sensors classify movement data during exercise and provide vibrotactile feedback with vibration actuators. Recent reviews differentiate the advantages and disadvantages of vibrotactile stimulation for wearable devices in home-based rehabilitation contexts. They illustrate, on the one hand, a potential of these technologies for hands-off contexts. They also show that empirically or theoretically guided rationales for developing feedback strategies are lacking [24,25]. Therefore, to design a feedback strategy, challenges from the perspective of interaction design and instructional psychology are considered.

Considerations from instructional psychology

There is a large body of research in instructional psychology regarding feedback design. In this field, the term feedback includes all post-response information that supports learners in their competence acquisition, i.e., regulating their learning process and mastering the learning task [26]. Feedback could be internal information or external information provided by an external source to the learner. The Interactive Tutoring Feedback model (ITF-model, [26]) postulates an integration of internal and external feedback to successfully support competence acquisition. One core ITF-principle for successfully supporting learning is strengthening the internal feedback (in motor learning for example the proprioception), through effective external feedback [27,28]. One should follow a strategic approach to design effective external feedback, i.e., a coordinated plan that implies decisions about specific feedback properties [26,27]. A feedback strategy integrates decisions about at least the following properties:

a) Under which situational and individual conditions is feedback provided? This requires analysis of task requirements, learning objectives, possible errors, and individual learners' skills, strategies, knowledge, motivation, and volition.

b) Which content should be provided by the feedback? Feedback always provides some kind of evaluative information (e.g., knowledge of result in terms of a single confirmation or rejection, or knowledge of the correct result). Furthermore, it can provide additional, elaborated information components. Elaborated components can offer information about task requirements, conceptual knowledge, error type, learning process, or strategies, i.e., information supporting the feedback receiver in further knowledge-gaining or learning process; or a combination of these components [26].

c) How is the feedback content presented using the formal and technical design properties that are available in a task context? Designing the presentation of the feedback contents includes making decisions on feedback timing, scheduling, and frequency, as well as the feedback modality. Concerning the feedback timing, literature differentiates between concurrent feedback, i.e., information delivered during task execution, and terminal feedback, i.e., information that is either delivered immediately or with delay after finishing a task. Feedback can be presented continuously after each event, or intermittently with a reduced frequency using for example fading-in or fading-out strategies. A technical feedback system can provide feedback in an unimodal vibrotactile way or in a multimodal way by supplementing for example vibrotactile feedback with other modalities.

Considerations from human-centered design

A challenge in the methods of design processes is the early integration of potential users. Human-centered design (HCD), originated in system design or product development, aims at increasing the usability of the end products. An important goal is to promote and improve the understanding of tasks, contexts, and users, as well as the resulting requirements [29,30,31]. This work is settled in the early phase of the development of a wearable feedback system, the unstructured and uncertain fuzzy front-end. So, HCD could be an effective method of improving the design process.

Research questions

The study aims to derive requirements for designing a vibrotactile feedback strategy to support patients in physiotherapy home exercises. To our knowledge, there is no research that combines knowledge from physiotherapists with considerations in instructional psychology.
The following research questions are addressed:

1) Which modality of feedback do physical therapists use?
2) Which feedback content do they provide?
3) When do physical therapists deliver and recommend feedback?
4) On which body locations do physical therapists deliver and recommend tactile feedback?

Methods

Study Design

A qualitative-descriptive study was conducted. We created a simulated training session of exercises for low back pain. In the first part, we observed how physical therapists delivered feedback to a simulated patient in a typical hands-on scenario. In the second part, we collected physical therapist recommendations for the most appropriate use of a wearable device to provide feedback to patients in a hands-off home-based scenario. This was achieved through interviews and observations.

Participants

Physiotherapists were recruited via e-mail and telephone contact, located in Dresden, Germany. A total of 30 facilities were contacted. During the initial contact, potential participants were informed about the aim of the study, the study procedure, and the data collection. The planned inclusion criteria of participants were at least three years of professional experience as a physiotherapist and having experience in treating with home exercises. The investigators and participants were unknown to each other except for the initial recruitment contact. Participants received an incentive of 15 € for their participation.
The research project was approved by the Ethics Committee of Technische Universität Dresden (SR-

EK-529112021) and follows the Declaration of Helsinki.

Material

The simulated training consisted of five home exercises for the treatment of nonspecific low back pain. We pre-selected home exercises based on a multicentre controlled trial [32]. Effective and frequently used exercises were evaluated and selected in interviews with three physiotherapists. To consider the practical application, further exercises for daily use were added by the physiotherapists. Requirements and typical errors for these five exercises were extracted. We trained a healthy simulated patient in performing correct and incorrect exercises with typical errors.

Before carrying out the examination, a pilot study was executed. The piloting was conducted with a trained physiotherapist with 10 years of professional experience; he fulfilled the inclusion criteria of the selected sample. The piloting aimed to check the comprehensibility and accuracy of the instructions, questions, interview, and home exercises, and to develop them further. After the piloting, questions for the semi-structured interview were added, and the execution of two exercises (rowing and squatting) was adjusted. In addition, the piloting enabled the research design to be checked and the implementation to be tested. Both the simulated patient and the researcher gained confidence in carrying out the research.

Hands-on session

The study took place at the participant's facilities. After completing demographic inquiries, participants were instructed to provide feedback to the simulated patient during the practical training session. They could decide independently on the type and timing of feedback. Each exercise started with a correct presentation of execution to illustrate the exercise target. No feedback should be given. Three runs of the same exercise followed in which feedback could be given, once without errors and twice with errors. One run corresponded to three repetitions of a movement pattern or 5 seconds of stabilization. This was followed by the presentation of a new exercise with three feedback runs of the new exercise (multimedia appendix A for a detailed description of the training session). If the participants gave feedback to the simulated patient, he reacted to this feedback and performed further repetitions in a corrected form or held the stabilization in a corrected position. The correction referred explicitly to the feedback and not to further errors not addressed. The interaction of participants and simulated patient was recorded with two video camcorders.

Hands-off session

After finishing the hands-on part, participants were informed about TaHiL interventions, and a simple demonstrator of a possible wearable feedback device was presented. Participants were instructed to imagine a hands-off scenario in which the simulated patient uses a wearable feedback device at home while doing their home exercises. After this instruction, the imagined hands-off scenario started. The same exercises used in the hands-on context were presented, also the same errors and repetitions. Participants should show where and when a tactile feedback system should deliver feedback while the simulated patient was doing the exercises. The whole session was recorded by video.

After finishing the hands-off part, an interview was conducted. Participants were interviewed to collect further recommendations for a feedback strategy. Since no validated questionnaires or interview guides existed for the present research interest, a semi-structured interview was developed and conducted. The interview mainly contained open-ended questions and was supplemented by individual closed-ended questions. The order and phrasing of the questions were flexible and could be adapted to the course of the interview. To be able to go into more detail about unforeseen, thematically relevant statements, additional ad-hoc questions were asked. The interview captured additions to the observed feedback data not covered in the observation (Table 1). It lasted approximately 15 minutes and was audio-recorded. A transcription was made with MAXQDA Plus 2022 (Release 22.2.0), and we used a content semantic transcription [33].

Table 1. Semi-structured interview schedule.

Topic	Questions and prompts
Task requirements	Please describe a possible behavior that could initiate vibrotactile feedback.
Localization	Besides the body localization you already showed, are there other body parts where vibrotactile feedback could be delivered?
Timing	To schedule the feedback to movement repetitions: When should vibrotactile feedback be presented?
Frequency	How often should vibrotactile feedback be delivered? Within a single training session? Within the training period? Which technique of reducing frequency is effective?
Content	Which Information should be given by vibrotactile feedback?
Individualization	Which feedback properties should be adaptable to individuals?

Data analysis

The aim of this data analysis was a systematic comparison of feedback properties, as well as the exploration of feedback properties in the context of the research questions. Therefore, a content structuring content analysis and a coding system were created [34]. The main and subcategories of the coding system were developed deductively based on theoretical and empirical preliminary work. Category names, content descriptions, examples, and decision rules were created for the respective categories. The data material of two participants was coded in a trial coding; subcategories were added inductively by subsumption [35]. The same coder repeated the trial coding after four weeks, agreement between these two codings was 87.85% (kappa = 0.88). A Kappa- value of K = 0.88 is interpreted as a strong agreement in the literature [36]. In addition, the category system was reviewed and discussed with a research team member. After the trial coding, definitions of main- and subcategories were modified, e.g., if segments could not be clearly assigned to a category or if segments were assigned to different categories when coded again. The main analysis was conducted with the complete and modified category system, and all data material was segmented and coded (Multimedia appendix B for the entire category system, including the definitions and examples).

In the hands-on context, feedback frequency, as well as feedback modalities, timing, content, and location, were coded. Movement repetitions formed the observation segments for feedback frequency. If feedback was detected, it was coded with the subcategories of Feedback modality, timing, and content. Each haptic feedback was additionally classified into the category feedback localization (Figure 1).
In the hands-off context, the behavioral sequences that were relevant were those associated with the use of a vibrotactile feedback system. Touches that presented information for using vibrotactile feedback systems and statements that referred to using a vibrotactile feedback systems formed relevant coding segments. If a coding segment was detected, it was classified into main- and subcategories (Figure 2-3).

Observational data was quantified. Relative frequencies of each subcategory were calculated per participant, for the entire sample means and standard deviations for each subcategory were calculated out of the participant based relative frequencies. Relative frequencies of combinations of subcategories per participant were calculated. Means and standard deviations of combinations of subcategories were calculated for the entire sample. Interview data were thematically summarized for the individual subcategories on a case-by-case basis and qualitatively analyzed. In addition, interrelations between the subcategories were analyzed. MAXQDA Plus 2022 (Release 22.2.0) and R Version 4.2.1 were used to analyze the data.

Figure 1. Category System for observations in the hands-on context.

Figure 2. Category System for observations in the hands-off context.

Figure 3. Category System for qualitative interview in the hands-off context.

Results

Participant statistics

Table 1 shows the demographic and occupational characteristics of participants. In total, nine participants participated in the study. Seven of them were trained physiotherapists, while the others were a sport trainer and a rehabilitation trainer. The sports therapist and the rehabilitation trainer stated that almost every patient was treated with home exercises. Therefore, we considered them as experienced.

Table 1. Demographic and occupational variables of participants.

Participant	Education	Working experience (years)	Treatment with home exercises	Age	Gender
P1	Physiotherapist	4	Almost every patient	23	Male
P2	Physiotherapist	24	For many patients	52	Male
P3	Physiotherapist	20	Almost every patient	43	Male
P4	Physiotherapist	16	Almost every patient	39	Male
P5	Sport therapist	5	Almost every patient	28	Female

P6	Physiotherapist	1	Almost every patient	26	Female
P7	Rehabilitation Trainer	8	Almost every patient	46	Female
P8	Physiotherapist	2.5	Almost every patient	26	Male
P9	Physiotherapist	8	Almost every patient	32	Male

possible answers “almost every patient”, “many patients”, “some patients”, “very few patients”

Feedback properties in hands-on context

In the hands-on context each movement repetition was categorized as either feedback given or no feedback was given. On average, the physical therapists provide feedback on 57.3% (SD 16.3), no feedback on 42.7% (SD 16.3) of movement repetitions.

Table 2 shows how often on average the different types of feedback content, modality and timing were used. On average, 50.2% of feedback content was coded as presentation of correct execution (SD 13.4). Elaborated and evaluative feedback was provided in smaller but similar amounts. Unimodal auditory feedback 51.9% (SD 12.1) or multimodal feedback with an auditory component was coded very frequently. The presentation of unimodal haptic feedback was an exception 0.8% (SD 1.2). The proportion of auditory-haptic feedback shows large interindividual differences (SD 24.4), i.e. some participants used this modality very often, some did not use it at all. Regarding feedback timing, concurrent feedback was mainly used 70.8% (SD 13.1).

Table 2. Means and SD of the event based relative frequencies (%) of feedback properties in hands-on context.

Feedback properties	Mean (SD)
Content	
Evaluative (confirmation)	28.3 (8.4)
Evaluative (rejection)	0.0 (0.0)
Presentation correct execution	50.2 (13.4)
Elaborated	21.5 (11.4)
Unassignable	5.6 (1.1)
Modality	
Visual	0.0 (0.0)
Auditive	51.9 (12.1)
Haptic	0.8 (1.2)
Auditive-visual	16.4 (16.0)
Auditive-haptic	29.2 (24.4)
Auditive-haptic-visual	1.9 (2.6)
Timing	
concurrent	70.8 (13.1)
Terminal immediately	27.1 (13.6)
Terminal delayed	2.3 (4.6)

Combination of feedback properties: content, timing, modality (hands-on)

To provide a more comprehensive account of feedback behavior, the combination of properties of feedback presentation were analyzed. Terminal feedback was often coded in combination with the auditory subcategory for 18.2% (SD 5.1). Simple confirming feedback was exclusively coded with auditory modality for 28.0% and the standard deviation was rather low 8.5%. Conversely, the presentation of correct execution as well as elaborated feedback were coded in combination with auditory, auditory-visual, and auditory-haptic modality, and relatively large standard deviations were detected. Evaluative confirming feedback was almost equally coded with the subcategories concurrent and immediate terminal feedback. Feedback that was coded as presentation of correct execution was often coded with the subcategory concurrent for 42.9% (SD 15.4) same for elaborated feedback with 14.2% (SD 9.5).

Feedback localization in hands-on and hands-off context

A feedback segment with haptic coding was additionally coded with the category localization of feedback. Figure 4 shows the means of the event based relative frequencies (%) of individual body regions, both for the hands-on and the hands-off context.

Figure 4. Means of relative frequencies (%) for body locations in hands-on and hands-off context. The error bars show the simple SD. The median of means is represented by the dotted line. Values bigger than the median are visualized as coloured areas in the figurines.

Combination feedback localization and task requirements (hands-off)

In the hands-off context each Feedback given by participants was coded for localization and task requirements. Feedback localizations were summarised to body regions. Feedback on muscle activity was frequently coded with the category abdomen and upper body. Coding with movement execution frequently occurred in combination with shoulder, pelvic gluteus, and arms. The starting position often occurred in combination with the head, shoulder, thigh, lower leg-knee-foot, pelvic gluteus, and lumbar spine regions. The coding evasive movement often occurred with the regions pelvic gluteus and shoulder.

Interview statements about Feedback properties, feedback localization, task requirements and individual parameter

Feedback properties: content, frequency, timing, modality, body localization (hands-off)

Table 3 outlines different types of evaluative feedback that were mentioned by eight out of nine physiotherapists. Four participants made statements about elaborated feedback content. Themes can be found in Table 3, all of them were connected to drive motor learning. Each participant recommended reduction in frequency, both in terms of repetitions of individual training sessions and over a longer training period of several weeks. Various techniques for implementing reduction were discussed. The rationale for starting with less feedback and increase over time pertained to proprioception refinement, initial acclimatization, and preventing sensory overload during the initial stages. Feedback fading was justified by the aim to cultivate participants' intrinsic body awareness and diminish reliance on the feedback system. There were no statements concerning the optimal fading rate. The indicated initiation periods for feedback fading varied, ranging from two to three to six weeks. Three participants specified that the error threshold should be modifiable in relation to the degree of deviation from the required joint angles or to the frequency of error repetition. Recommendations about when, how, and where feedback could be presented is also presented in Table 3.

Adaptation of feedback properties to task requirements and individual parameter (hands-off)

Table 3 outlines the requirements of physical therapists referring to the adaption of feedback properties to task requirements and individual parameters.

The presentation of correct execution can include various task requirements, like muscle activation, spatial movement execution, finding the correct initial position, velocity of movements, and persistence in training. The specific task request associated with a particular (haptic) signal would depend on the individual interpretation of the patients.

While all participants expressed unanimous support for feedback frequency reduction, two individuals noted the decline in endurance and muscle activity during a training session. They recommended providing explicit feedback on exercise repetitions and fatigued muscles. Three participants mentioned that physical conditions could influence the feedback frequency. Less feedback should be given in case of poorer conditions due to illness or age. However, this also depends on the error pattern; potentially damaging errors, e.g., severe joint overload due to malposition or injuries, should be corrected more quickly. The use of self-controlled feedback is related to motivation to improve oneself. Some of the physical therapists described that this motivation is not present in most patients so self-controlled feedback should not be used.

Feedforward information refers primarily to muscle activity as well as the starting position. Concurrent feedback refers additionally to movement execution.

Six participants emphasized that visual or auditory feedback should pertain to the initial starting position. In parallel, four participants highlighted the appropriateness of haptic feedback for guiding movement execution and indicating muscle activity.

Half of the participants advocated providing vibrotactile feedback in specific anatomical regions, including the upper back-shoulder and lower back areas. An insightful suggestion emerged from one participant who underscored the necessity for individually tailored actuator settings in these regions, considering physical conditions such as kyphosis or lordosis tendencies and individual sensitivity to tactile stimuli in the scapula region. Additionally, four participants endorsed the application of vibrotactile cues to the thigh and gluteus-pelvis region. Opinions diverged among participants concerning feedback localization for the knee-leg-foot, upper extremities, and neck-head regions. Notably, two participants opposed tactile feedback in the neck-head area.

Four of seven participants recommended the adaptability of localization to individual needs, enabling flexible actuator configurations based on physical attributes or personalized training progress. A conceptual differentiation between static and mobile muscles during exercise execution was highlighted by three participants, prompting the suggestion for diverse forms of feedback (e.g., variation in frequency) to accommodate these distinctions.

The results show that four participants associated the initial starting position with upper extremities and two with lower extremities. Muscle activity was mentioned in connection with feedback localization in the abdomen region by three participants and in the gluteus-pelvis region by two participants. Additionally, the lower back and the thighs were indicated as regions for feedback on muscle activity.

Table 3. Shows feedback properties (content, frequency, timing, modality, body localization) that were named by physiotherapists in the qualitative interview. Themes were summarized and listed. Relations of feedback properties to specific task requirements or individual parameter are shown. The number in brackets indicates the number of participants naming the topic.

Feedback properties	Themes	Task requirements	Individual parameter
Content			
Evaluative	Unspecific confirmation (3)		
	Specific confirmation (1)	Spatial movement execution (1)	
	Unspecific error signaling (2)	Initial position (2)	
		Spatial movement execution (1)	
	Presentation of correct execution (8)	Muscle activity (4)	Feedback interpretation (2)
		Spatial movement execution (4)	
		Initial Position (3)	
		Motion velocity (2)	
		Persistence in training/repetitions (2)	
Elaborated	Cues for self-monitoring (1)		
	Supporting try and error (1)		Feedback perception (1)
	Presenting task relevant hints (3)	Initial Position (1)	
		Muscle Activity (2)	
		Breathing (1)	
	Summative error feedback (1)		
Frequency			
Reduced	Fading within training period (6) Fading within single training session (2) Increasing within single training session (4)	Persistence in training/repetitions (1) Muscle activity (2)	Level of motor skills (1) Physical condition (Age, Diseases) (4)
	Self-controlled		Individual motivation for exercising
Timing			
Feedforward		Initial Position (3)	
		Muscle activity (3)	
Concurrent		Initial Position (1)	
		Muscle activity (3)	
		Spatial movement execution (1)	
Modality			
Visual or auditive		Initial position (6)	
		Evasive movements (1)	
		Spatial movement execution (1)	
		Persistence in training/repetitions (1)	
		Motion velocity (1)	
Haptic		Initial position (1)	
		Evasive Movements (1)	
		Spatial movement	

		execution (4)	
		Muscle activity (4)	
Multimodal		Evasive movements (1)	
Body Localization			
Shoulder – Upper back		Evasive movements (1)	Physical condition (anatomy) (1)
			Feedback perception (1)
Lower back		Muscle activity (1)	Physical condition (anatomy)
		Evasive movements (1)	
Gluteus – Pelvis		Muscle activity (2)	
		Spatial movement execution (1)	
Tigh		Muscle activity (2)	
		Initial position (1)	
Knee – Leg – Foot		Initial position (4)	Physical condition (anatomy) (1)
			Feedback perception (1)
		Spatial movement execution (1)	
Arm – Hand		Initial Position (4)	
		Spatial movement execution (1)	
Neck – Head			
Abdomen		Muscle activity (3)	Feedback perception (1)
Unspecific			Physical condition (weight, Diseases)

Combination of feedback properties: content, timing, modality (hands-off)

There were single statements about when and how simple evaluative feedback should be presented. Unspecific confirmation could take the form of the vibrotactile cue, presented concurrent or terminal delayed. Unspecific error signaling could be presented concurrently as vibrotactile, auditive, or visual information. The presentation of correct execution was exclusively coded as concurrent information, delivered haptically, auditorily, visually, or through a combination of modalities. We found limited comments regarding the presentation of elaborated feedback. One participant suggested terminal delayed visual or auditory feedback concerning frequent errors: "Yes, you could also show at the end that you had 90% of 100% correct posture. Or pay more attention to your abdominal tension in the next session because it needs a lot of stimuli now" (participant 6). Additionally, multimodal concurrent or visual concurrent relevant hints could be presented pertaining to task-specific muscle activity (illustrated, for instance, by color-coded body regions).

Discussion

This paper aimed to derive requirements for a vibrotactile feedback strategy for home exercises. We gained initial insights into the provision of feedback and recommendations for a feedback strategy. Hypothesis-driven empirical studies based on initial approaches should follow. A strength of this work is the combination of design-driven methodology with respect to empirically and theoretically relevant insights of instructional psychology. The following sections will discuss the results along the studied feedback properties. Limitations and future work will be outlined.

Feedback content

In the hands-on context, the presentation of the correct execution was frequently given, somewhat less frequently simple confirmatory feedback or elaborated feedback. The hands-off results showed few recommendations on the presentation of elaborated information, some on the use of presentation of correct results in relation to different task requirements. For the design of the feedback strategy, it seems relevant to decide which task requirements should be covered in terms of content (e.g. muscle activity, spatial movement accuracy, velocity). Literature presents mixed results regarding the effectiveness of informational feedback, confirmatory feedback, or a combination of both in facilitating motor learning [37]. What content is effective depends on moderating factors such as task difficulty and skill level. The informational property of feedback becomes more important as task difficulty increases [38]. Especially for people with low skill levels, the presentation of information about solutions and ways of solving problems, as well as elaborated feedback, seems to be effective [39,40].

To design a feedback strategy for home exercising it seems worthwhile to analyze the effects of feedback content in different learning states. Whether pain patients could benefit from elaborated feedback should be determined in further studies. Therefore, interaction effects should be considered. If, for example, elaborated feedback is combined directly with the presentation of the target performance, elaborated information has no additional effect [41].

The qualitative data can also identify reasons against the use of elaborated feedback. The participants mainly mentioned structural aspects such as the limited time frame of a treatment or the patients' goal and motivation to become pain-free quickly without wanting to achieve long-term learning effects. Further studies should examine the user acceptance and usability of the feedback strategy.

Feedback frequency

Participants recommended and showed reduced feedback frequency, they did not provide feedback for every movement repetition and error. This aligns with previous research linking improved motor performance with decreased feedback frequency during training and retention [42–45]. Conflicting results show no effects of reduced feedback as well as effects dependency on task complexity, learning phase, and individual learner characteristics [2,43,44,46–48]. Physical therapists aimed to reduce system dependency and train proprioception. This also matches previous literature, which postulates that by reducing the frequency of feedback, the dependence on extrinsic feedback is reduced and thus intrinsic sources of feedback can be used [2,47]. Participants discussed reducing feedback frequency within a training session and over a more extended training period, suggesting adaptability of the feedback strategy to both time frames. Externally controlled feedback was recommended, while self-controlled feedback was neither used nor suggested. The empirical literature does not clearly indicate a preferred technique for reducing feedback frequency [46,49].

Individual factors, such as susceptibility to errors, patient age, and physical condition, were identified as potential influences on feedback reduction. These recommendations are partly in line with previous research literature. For example, the optimal reduction in feedback frequency is related to the feedback recipient's motor skill level and is influenced by perceived task difficulty [50]. For the design of a feedback strategy, adapting the feedback frequency to these parameters seems relevant.

Feedback timing

Results show that physical therapists provided frequently and unanimously recommended concurrent feedback. Delivering concurrent feedback can hinder learning but can support the performance of motor skills [17,46]. To apply a feedback strategy the timing of feedback should be connected to its goal: performance enhancing or motor learning.

In addition, the level of motor skills should be considered. For people with low motor skill levels, presenting concurrent feedback is initially beneficial [51]. So there is a need of analyzing the skill levels of patients.

Furthermore, physical therapists recommended the presentation of feedforward information. They suggest to present information related to muscle activity or the starting position.

Feedback modality

Physical therapists provide auditive feedback or multimodal feedback with auditive feedback component. So there is a need to integrate or translate this verbal information into vibrotactile feedback.

To translate verbal information unimodal vibrotactile feedback can be presented with solid links to verbal information, e.g. to movement directions in different planes. Literature describes this as a push or pull mechanism, moving the body away from the vibration or following the vibration [18,46]. Previous research shows individual preferences for intelligibility and the use of these mechanisms [18,52,53]. By activating multiple actuators, spatiotemporally bound vibration patterns can instruct movements [54].

To integrate verbal information multimodal feedback can be used, this can cover the entire usage behavior that we found in our results (e.g. some participants used certain modalities very often or very little). Literature also shows the benefits of providing multimodal feedback on motor performance and learning [15,55,56]. Our results show that visual or auditive information were connected to various task requirements. Six participants connected them to correction of initial position. Four participants connected tactile cues with spatial movement and muscle activity. To design a feedback strategy, it seems useful to conduct studies that investigate the advantages of unimodal auditory vs. haptic vs. multimodal feedback in relation to initial position, spatial movements, and muscle activity.

Integration of content, modality, and timing

It was found that simple confirmative feedback was mainly presented auditorily, concurrent or terminal to a movement execution. The presentation of correct execution as well as elaborated feedback was mainly presented concurrently, in some cases terminally. To further develop the feedback strategy, we can define a type of feedback: confirmatory auditory feedback. It is then considered and needs to be studied whether this type of feedback differs from the presentation of correct execution and elaborated feedback.

Feedback localization

Feedback in the abdominal area was associated with muscle activity. Spatial motion accuracy was often coded with the pelvis, shoulder, or arm area. The starting position was frequently coded with head, shoulder, thigh, lumbar spine, pelvis, and knee. Thus, we see a tendency for feedback on muscle activity and spatial motion accuracy relating more to specific body parts than feedback on the starting position. A request for the feedback strategy could be to make vibrotactile cues distinguishable between muscle activity and spatial movements, regarding the mentioned body areas. Both in the hands-off context and from the interview data, haptic stimuli appear less set or intended on the forearm, hands, lower legs, and feet. Further studies should investigate whether auditory or visual information is sufficient to correct the positions of extremities.

Limitation

Studies show that control of the spine [57] and trunk [58] can differ between patients and healthy persons. In this study, a healthy person presented the home exercises and simulated typical movement and error patterns of back pain patients. Thus, the comparability of feedback behavior in our study and towards a patient may be limited. Therefore, engaging in hypothesis-driven research on patient samples is a necessity. Further, we use five home exercises used in treatment of back pain, hence the findings could not be generalized to a large extent. One also should consider that the feedback behavior may have been influenced by the presence of the experimenter or by direct observation using cameras. Socially desired behavior, which manifested itself in the fact that the participants wanted to act as correctly as possible, could have led to distortions of natural or intuitive feedback. In some cases, the participants expressed that they were under pressure to act. Further studies should be conducted in the field of practice.

It should be noted that this study focuses on spatial exercise accuracy, measurable by whether the body movement path performed corresponds to the prescribed one. Other relevant factors that can be used to measure whether exercises are performed as agreed as upon with health care providers are temporal factors: repetitions of the exercises, repetitions of the exercise sets, repetitions of the training, and the velocity of movements [59]. No temporal errors were included in the study design. Hence, feedback to these factors was rarely provided in the hands-on context. In the interview, in the hands-off context, information about task requirements was gained, but it can be assumed that the study design in the hands-on context influenced the interview answers. In the sense that physical therapists did not consider temporal factors to the same extent as spatial factors. Further studies should consider these factors for designing a holistic feedback strategy.

Numerous factors influence whether home exercises are performed correctly, e.g. memory capacity, motivation, attitudes, volition, or training conviction of the patients [59]. For designing an effective feedback strategy, the function of feedback should be differentiated. Further research is needed to determine how feedback can support the prescribed execution of home exercises.

Practical implementation

First, it should be noted that a feedback strategy should be flexible and adaptable to the patient. The present work suggests that a feedback system should consider the baseline of motor skill expression (e.g., in the form of error frequency). The error thresholds should be set according to this baseline; thus, the feedback frequency can be influenced. Ideally, a feedback system can measure learning progress and adjust feedback frequency. In terms of feedback content, a language needs to be developed that patients can understand, both in terms of tactile presentation of the correct execution of exercise and in terms of confirmation of goal-directed action. Whether the presentation of elaborated information can increase the effectiveness of the feedback strategy needs to be investigated in subsequent studies. Although the focus of this paper is on a vibrotactile feedback strategy, the addition of auditory cues or visual information seems advisable. Suitable interfaces for the presentation of auditory and visual signals should be developed. Concurrent presentation of feedback is recommended. This feedback is presented vibrotactilely on muscle activity or spatial motion accuracy. For this purpose, actuators should be positioned primarily in the regions of the gluteus, pelvis, spine, deltoid, trapezius, abdominals, lateral to the trunk, thigh, and knee. Another implication for practice is the possibility of providing feedforward information on task-relevant musculature and the starting position.

Conclusion

The present work highlights that reduced feedback frequency, differentiated feedback content, multimodal feedback, and trunk-proximal vibrotactile feedback were recommended by physical therapists for a technical feedback system for the correct performance of home exercises. The results of the present study provide an overview of relevant feedback characteristics and can serve as a starting point for further empirical research. Hypothesis-driven studies in sufficiently large patient samples should follow for the further development of a feedback strategy. Research-relevant topics are, on the one hand, the perception, interpretation, and reaction patients to vibrotactile feedback. On the other hand, the integration of a technical-economic perspective about cost factors, hardware and software solutions.

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Conflict of Interest

None declared.

Abbreviations

HCD: Human-centred design
ITF: Interactive Tutoring Feedback
TaHiL: Tactile Internet with Human in the Loop

Multimedia Appendix 1

Description of exercise execution

Multimedia Appendix 2

Descriptions of category systems (hands-on and hands-off)

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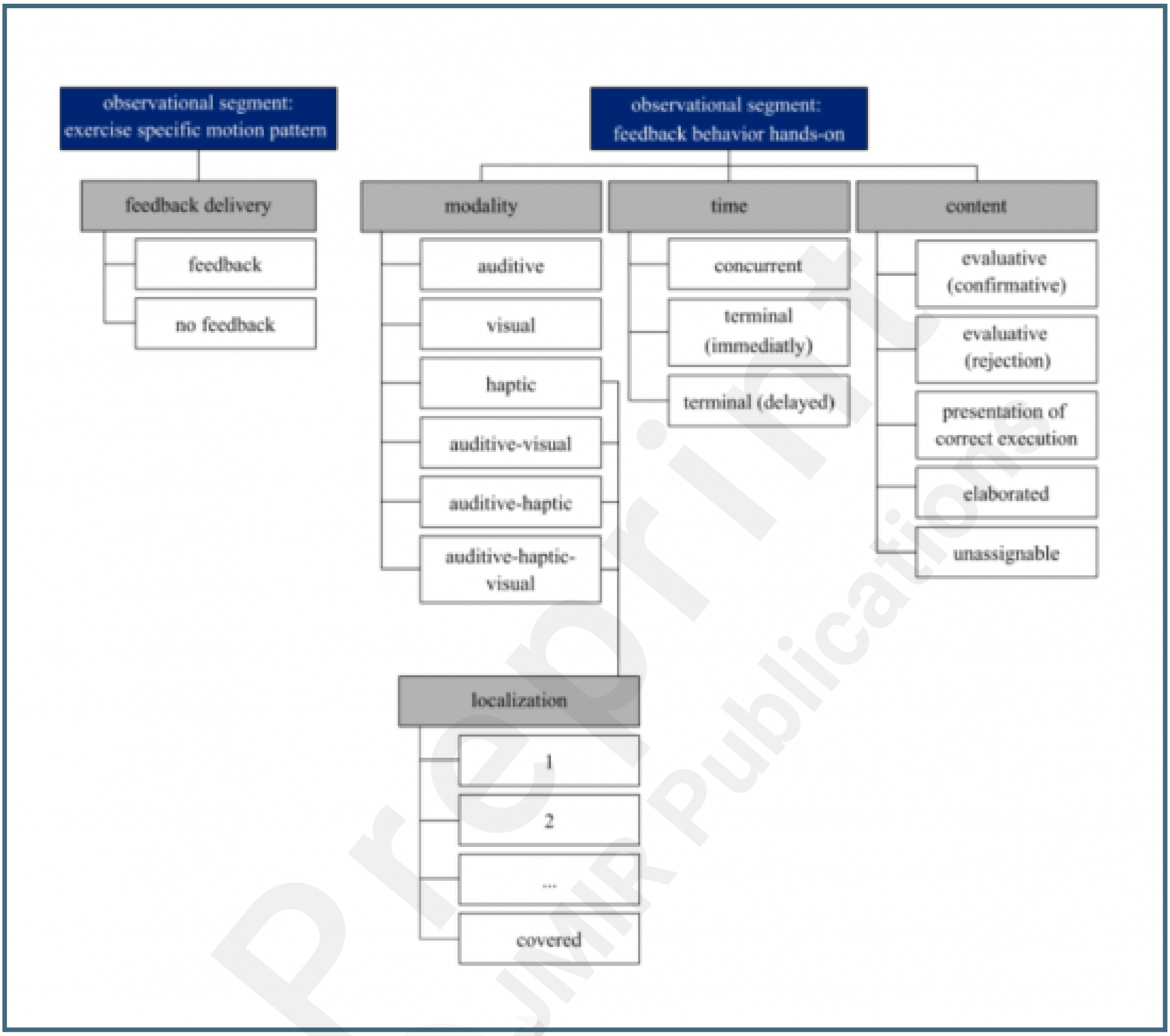
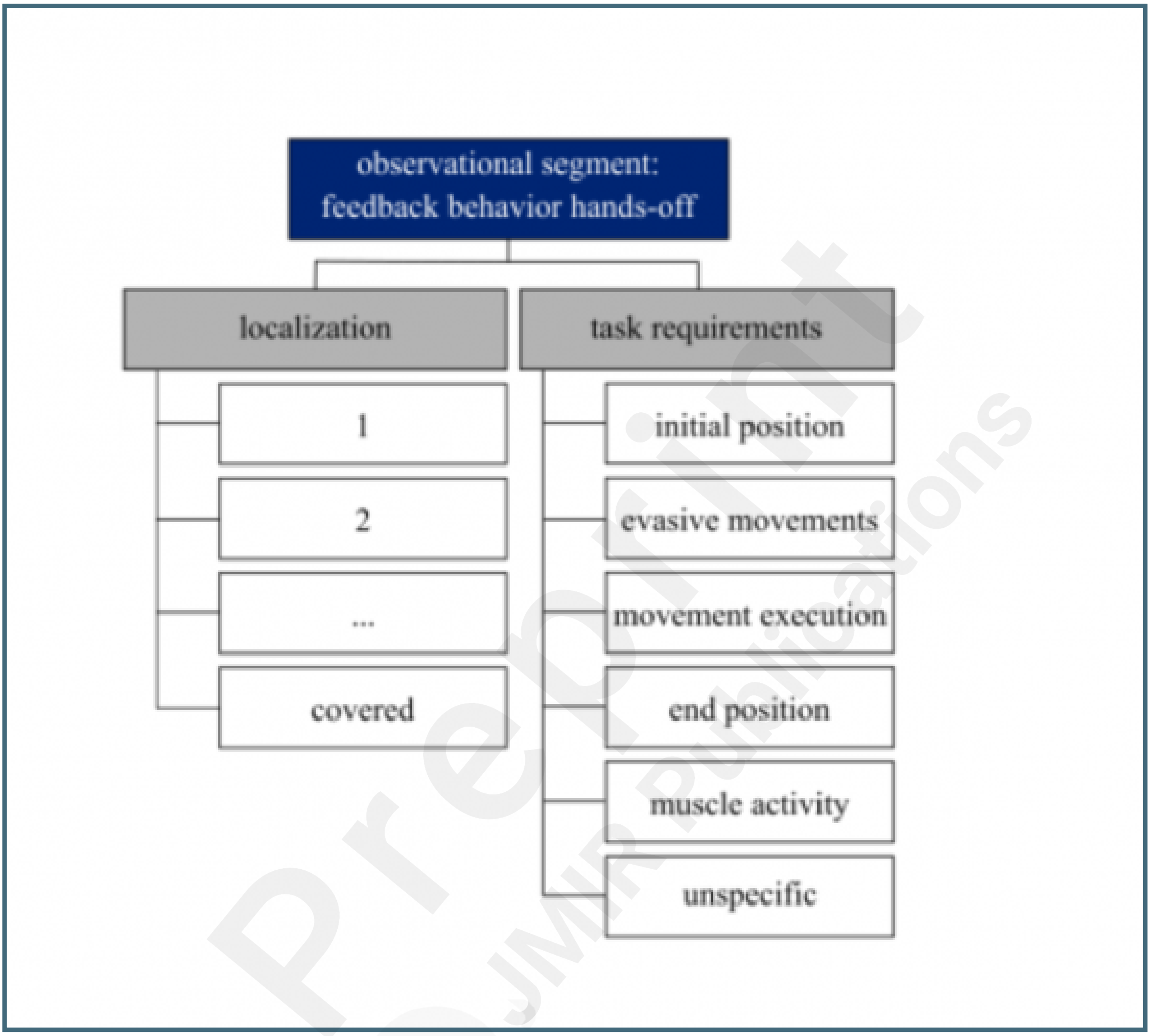
Supplementary Files

Figures

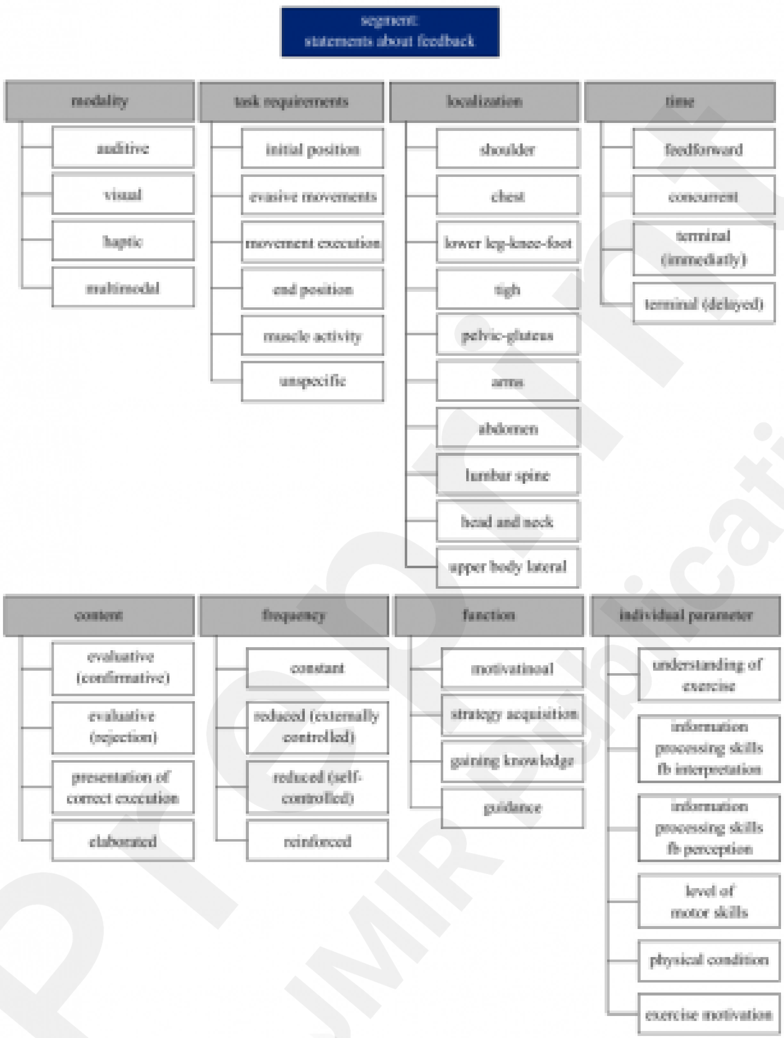
Category System for observations in the hands-on context.



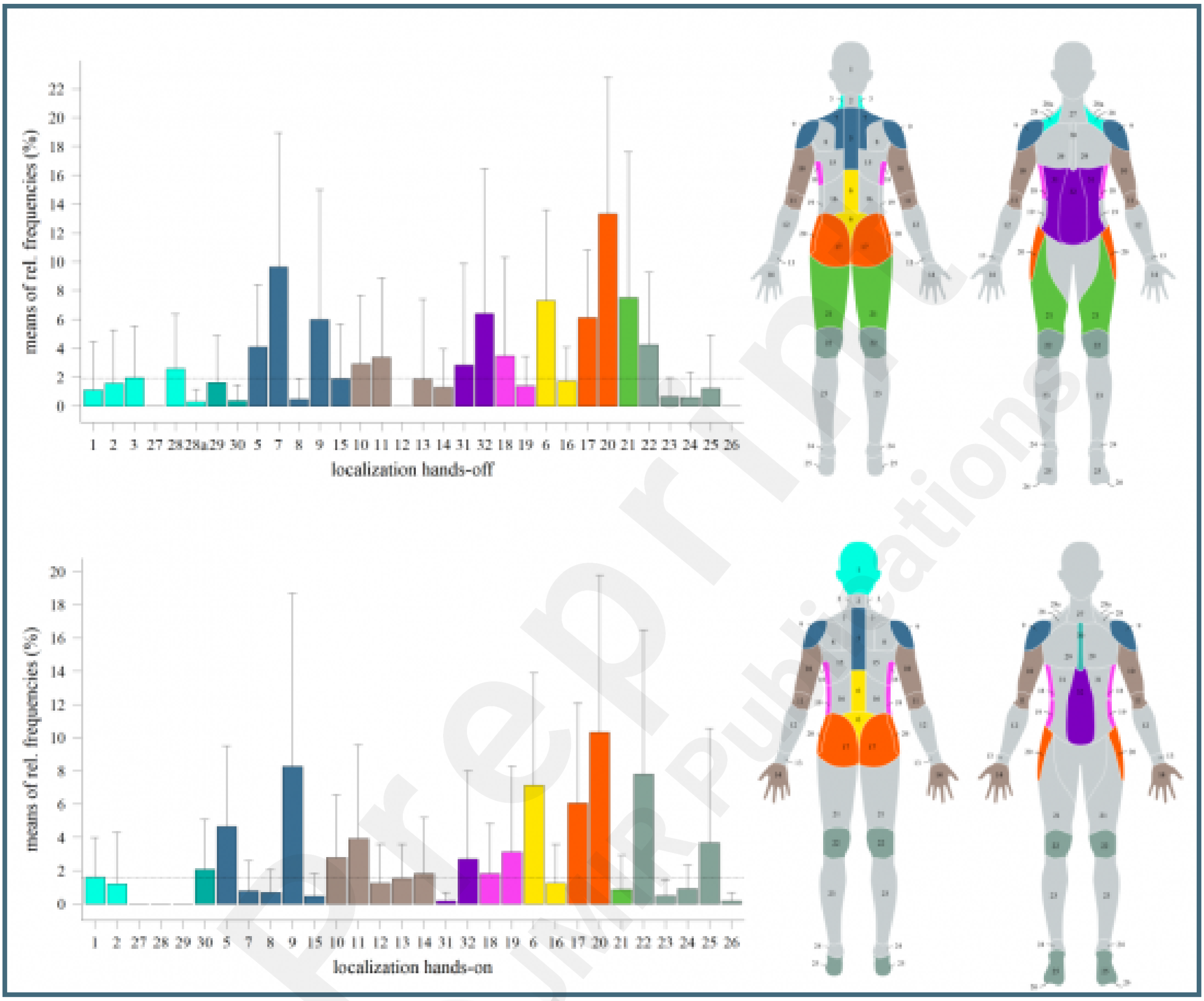
Category System for observations in the hands-off context.



Category System for qualitative interview in the hands-off context.



Means of relative frequencies (%) for body locations in hands-on and hands-off context. The error bars show the simple SD. The median of means is represented by the dotted line. Values bigger than the median are visualized as coloured areas in the figurines.



Multimedia Appendixes

Description of exercise execution.
URL: http://asset.jmir.pub/assets/bc2f7915f8247e5f679b037221a90774.doc

Descriptions of category systems (hands-on and hands-off).
URL: http://asset.jmir.pub/assets/ab302f532af9cda00bca98820f7199f0.doc