

Identifying Design Requirements for an Interactive Physiotherapy Dashboard with Decision Support for Clinical Movement Analysis of Musicians with Musculoskeletal Problems: Qualitative User Research Study

Eduard Wolf, Karsten Morisse, Sven Meister

Submitted to: JMIR Human Factors
on: August 02, 2024

Disclaimer: © The authors. All rights reserved. This is a privileged document currently under peer-review/community review. Authors have provided JMIR Publications with an exclusive license to publish this preprint on its website for review purposes only. While the final peer-reviewed paper may be licensed under a CC BY license on publication, at this stage authors and publisher expressly prohibit redistribution of this draft paper other than for review purposes.

Table of Contents

Original Manuscript..... 5

Supplementary Files..... 42

 Multimedia Appendixes..... 43

 Multimedia Appendix 1..... 43

 Multimedia Appendix 2..... 43

 Multimedia Appendix 3..... 43

Identifying Design Requirements for an Interactive Physiotherapy Dashboard with Decision Support for Clinical Movement Analysis of Musicians with Musculoskeletal Problems: Qualitative User Research Study

Eduard Wolf^{1, 2, 3} MSc; Karsten Morisse³ Prof Dr; Sven Meister^{1, 2} Prof Dr

¹ Healthcare Department Fraunhofer Institute for Software and Systems Engineering Dortmund DE

²Health Informatics Faculty of Health, School of Medicine Witten/Herdecke University Witten DE

³Department of Computer Science and Media Faculty of Engineering and Computer Science Osnabrück University of Applied Sciences Osnabrück DE

Corresponding Author:

Eduard Wolf MSc

Healthcare Department
Fraunhofer Institute for Software and Systems Engineering
Speicherstraße 6
Dortmund
DE

Abstract

Background: Musculoskeletal disorders are common among musicians, requiring precise diagnostic and therapeutic approaches. Physiotherapists face unique challenges due to the complex relationship between musculoskeletal health and the demands of musical performance. Traditional methods often lack the necessary precision for this specialized field. Integrating Clinical Decision Support (CDS) tools with Clinical Movement Analysis (CMA) could improve diagnostic accuracy and therapeutic outcomes by offering detailed biomechanical insights and facilitating data-driven decision-making.

Objective: This study aimed to identify design requirements for a specialized CDS tool incorporating CMA to support physiotherapists in diagnosing and treating musculoskeletal disorders in musicians, thereby improving diagnostic accuracy, therapy effectiveness, and patient outcomes.

Methods: A qualitative user research study was conducted, utilizing Human Factors Engineering methods from problem-driven research, user-centered design, and decision-centered design. Data collection included a domain-specific literature review, workflow observations, and focus group discussions with domain experts, including three musicians' physiotherapists and a movement scientist. This qualitative data was triangulated to characterize the domain, identify the CMA workflow, user needs, key cognitive tasks, and decision requirements. These insights were translated into concrete design requirements for a CDS tool.

Results: A workflow for integrating musician-specific CMA into physiotherapy was established. Twenty-one user requirements, seven key cognitive tasks, and five key decision requirements were defined, along with forty-nine design seeds, which informed the design requirements for the CDS tool. Key features identified include: (1) efficient integration of musician-specific biomechanical findings into therapy; (2) combining heterogeneous data types for holistic assessment; (3) providing an adaptive overview of patient-related information; (4) utilizing adequate visual representations and interaction techniques; (5) facilitating efficient visual-interactive analysis of findings and treatment results; (6) enabling preparation and export of therapy findings and analysis results. Additionally, eleven technical prerequisites and fourteen decision support recommendations were identified. These requirements will guide the design and development of a CDS tool featuring advanced visualization tools, interactive data exploration capabilities, and contextual integration of clinical and biomechanical data.

Conclusions: A specialized CDS tool incorporating CMA data holds significant potential to enhance decision-making in musicians' physiotherapy. By addressing cognitive demands and integrating advanced visualization techniques, the tool can support physiotherapists in making more accurate assessments, potentially improving patient outcomes, reducing injury recurrence, and supporting musicians' career longevity. Ongoing research is essential to refine the tool and validate its clinical

effectiveness. Future studies should incorporate advanced analytics and explore broader therapeutic applications to enhance its impact.

(JMIR Preprints 02/08/2024:65029)

DOI: <https://doi.org/10.2196/preprints.65029>

Preprint Settings

1) Would you like to publish your submitted manuscript as preprint?

✓ **Please make my preprint PDF available to anyone at any time (recommended).**

Please make my preprint PDF available only to logged-in users; I understand that my title and abstract will remain visible to all users.

Only make the preprint title and abstract visible.

No, I do not wish to publish my submitted manuscript as a preprint.

2) If accepted for publication in a JMIR journal, would you like the PDF to be visible to the public?

✓ **Yes, please make my accepted manuscript PDF available to anyone at any time (Recommended).**

Yes, but please make my accepted manuscript PDF available only to logged-in users; I understand that the title and abstract will remain visible.

Yes, but only make the title and abstract visible (see Important note, above). I understand that if I later pay to participate in <https://preprints.jmir.org/preprint/65029>

No. Please do not make my accepted manuscript PDF available to anyone. I understand that if I later pay to participate in <https://preprints.jmir.org/preprint/65029>

Original Manuscript

Original Paper

Title

Identifying Design Requirements for an Interactive Physiotherapy Dashboard with Decision Support for Clinical Movement Analysis of Musicians with Musculoskeletal Problems: Qualitative User Research Study

Authors:

Eduard Wolf, MSc.^{1,2,3}

E-Mail: eduard.wolf@isst.fraunhofer.de

ORCID: 0000-0003-0237-1342

Karsten Morisse, Prof. Dr.²

E-Mail: k.morisse@hs-osnabrueck.de

ORCID: 0000-0002-9217-8943

Sven Meister, Prof. Dr.^{1,3}

E-Mail: sven.meister@uni-wh.de

ORCID: 0000-0003-0522-986X

¹Health Informatics, Faculty of Health, School of Medicine, Witten/Herdecke University, Witten, Germany

²Dept. of Computer Science and Media, Faculty of Engineering and Computer Science, University of Applied Sciences, Osnabrück, Germany

³Fraunhofer Institute for Software and Systems Engineering, Dortmund, Germany

Corresponding author:

Eduard Wolf, MSc.

Fraunhofer Institute for Software and Systems Engineering ISST

Speicherstraße 6, D-44147 Dortmund, Germany

Phone: +49 231 976 77 450

Email: eduard.wolf@isst.fraunhofer.de

Keywords

Physical Therapy; Clinical Movement Analysis; Clinical Decision Support; Performance-related Musculoskeletal Disorders; Requirements Engineering; Human Factors Engineering; Design Study Methodology; Problem-Driven Research; User-Centered Design; Decision-Centered Design

Abstract

Background: Performance-related musculoskeletal disorders (PRMDs) are common among musicians, requiring precise diagnostic and therapeutic approaches. Physiotherapists face unique challenges due to the complex relationship between musculoskeletal health and the demands of musical performance. Traditional methods often lack the necessary precision for this specialized field. Integrating Clinical Movement Analysis (CMA) with Clinical Decision Support (CDS) could improve diagnostic accuracy and therapeutic outcomes by offering detailed biomechanical insights and facilitating data-driven decision-making.

Objectives: This study aimed to identify design requirements for an interactive dashboard that aids clinical decision making by incorporating CMA to assist physiotherapists in managing musculoskeletal disorders in musicians.

Methods: A qualitative user research study was conducted, utilizing Human Factors Engineering methods from problem-driven research, user-centered design, and decision-centered design. Data collection included a domain-specific literature review, workflow observations, and focus group discussions with domain experts, including four physiotherapist experts and an expert for clinical reasoning and applied biomechanics. This qualitative data was triangulated to characterize the domain, identify the CMA workflow, user needs, key cognitive tasks, and decision requirements. These insights were translated into concrete design requirements.

Results: A workflow for integrating musician-specific CMA into physiotherapy was established. Twenty-one user requirements, seven key cognitive tasks, and five key decision requirements were defined, along with forty-nine design seeds. Key features identified include: (1) efficient integration of musician-specific biomechanical findings into therapy; (2) combining heterogeneous data types for holistic assessment; (3) providing an adaptive overview of patient-related information; (4) utilizing adequate visual representations and interaction techniques; (5) facilitating efficient visual-interactive analysis of findings and treatment results; (6) enabling preparation and export of therapy findings and analysis results. Additionally, fourteen CDS recommendations and eleven technical prerequisites were identified. These requirements guide the design of an interactive tool featuring advanced visualization, interactive data exploration capabilities, and contextual integration of clinical and biomechanical data.

Conclusions: An interactive physiotherapy dashboard with CDS incorporating CMA data holds significant potential to enhance decision-making in physiotherapy for musicians with PRMDs. By addressing cognitive demands and integrating advanced visualization techniques, the tool can support physiotherapists in making more accurate assessments, potentially improving patient outcomes, reducing injury recurrence, and supporting musicians' career longevity. Ongoing research is essential to refine such a tool and validate its usability, decision support, and clinical effectiveness. Future work should explore advanced analytics, adapt to various CMA systems, and expand applications across musicians and therapeutic domains to enhance its impact.

Introduction

Background

Musculoskeletal disorders are common among musicians due to repetitive movements, muscle strain, poor posture, and intensive practice, affecting their ability to perform and sustain careers [1–3]. At least 50% of musicians suffer from *performance-related musculoskeletal disorders (PRMDs)*, experiencing pain and other symptoms that impair performance [4–6]. However, targeted therapy is underused, and specialized assessment and treatment strategies are needed (cf. [7,8]).

Musician-specific physiotherapy is beneficial for identifying and treating these issues, focusing on aspects of posture, movement behavior, and musical expression that affect health [8–10]. Effective treatment requires a thorough understanding of musician-specific characteristics and identification of functional disorders in the musculoskeletal system through clinical neuro-orthopedic examinations and analyses of the musician's movement while performing [11].

In physiotherapy, clinical reasoning is essential for decision-making, often using a hypothetical-deductive method [12]. Accurate diagnostics are crucial to prevent misjudgments [13], and comprehensive information gathering is vital for effective therapy planning [14,15]. Technology-driven assessments can enhance diagnostic accuracy, moving beyond subjective methods and trial-and-error approaches [16].

Clinical Movement Analysis (CMA) provides objective, quantifiable data on functional disorders, supporting personalized medicine [11,17] and offering physiotherapy applications that conventional assessments cannot achieve [18,19]. As an apparatus-based biomechanical analysis for individualized functional diagnostics, CMA employs techniques such as motion capture and electromyography (cf. [20,21]). It helps evaluate complex movements during performance, allowing for the identification of aberrant postures and movements contributing to PRMDs in musicians [22–24]. Thus, CMA aids in diagnosing functional disorders, planning individualized therapy, and monitoring therapeutic measures [17,19,25], minimizing the risk of false results [26,27].

The *RefLabPerform* project [28] aims to develop a reference laboratory for PRMD assessment in musicians, integrating CMA with physiotherapeutic assessments, which will be implemented at the *Institute for Applied Physiotherapy Osnabrück (INAPO)*. Advanced instruments will be used by specialists for musician-specific CMAs, with results provided to physiotherapists for further clinical evaluation.

However, interpreting CMA data requires expertise and time, presenting challenges for clinical practice, highlighting the need for efficient, intuitive presentation for analysis and decision making [11,29,30]. Current tools for biomechanical analysis lack guidance for musicians' physiotherapy, leading to concerns about accuracy and usability [30,31].

A tailored health technology for musicians' physiotherapy is essential to efficiently record, process, provide, analyze, and interpret musician-specific CMA data for routine use. Hereby, an interactive dashboard with *Clinical Decision Support (CDS)* can improve diagnostics by integrating CMA findings, facilitating comprehensive decision-making and effective therapies [32]. Adapting research approaches from health while considering physiotherapy-specific conditions will ensure the tool aligns with the clinical workflow, balancing perceived benefit, effort, and costs [16,33].

Human factors and CDS design

Human Factors Engineering (HFE) is crucial for designing interactive health technologies and CDS tools, focusing on usability and workflow integration for decision support (cf. [34–36]). Effective CDS requires speed, efficiency, meaningful alerts, consistency, and logical grouping with intuitive interface design [37–40]. Hence, designing such a technology must address user needs, working environments, cognitive demands, decision-making requirements, and advanced interactive

visualizations for data analysis.

Three HFE approaches—*Design Study Methodology (DSM)*, *User-Centered Design (UCD)*, and *Decision-Centered Design (DCD)*—provide guidance for this. DSM is a problem-driven research paradigm focused on creating innovative visualization solutions through iterative collaboration with domain experts to address real-world problems [41]. UCD emphasizes understanding user tasks, goals, and needs by involving users from the beginning, which informs the specification of user requirements and guides the design process [42]. DCD aims to improve decision-making in critical scenarios, such as medical diagnosis, by enhancing human decision-making [43,44]. Cognitive task analysis identifies key cognitive demands and translates them into decision requirements, guiding the design process to improve clinical performance [45]. These approaches share a human-centered, iterative, and multi-stage methodology, leveraging in-depth analysis and expert contributions, while each addresses distinct aspects of the design process.

Objectives

The study aimed to identify design requirements for an interactive tool, specifically a physiotherapist dashboard, that aids clinical decision-making for musculoskeletal problems in musicians within the *RefLabPerform* project. This involved considering the working environment, clinical procedures, and user needs from the beginning, and gathering detailed information on how decision-making in musicians' physiotherapy can be supported technically, especially with the integration of CMAs.

To achieve this, requirements elicitation methods from three HFE approaches—DSM, UCD, and DCD—were followed to comprehensively describe the domain and the underlying problem, resulting in well-informed requirements and recommendations. This approach is expected to enhance usability and acceptance, improve user efficiency and accuracy, and reduce the cognitive workload of the future tool.

Methods

Research approach

This qualitative user research study followed a problem-driven research paradigm and formed part of the initial *Domain Characterization and Analysis* phase within a larger design study. It systematically integrated elements from DSM, UCD, and DCD to elicit and structure design requirements for an interactive dashboard with CDS functionality in physiotherapy (see Figure 1). The requirements elicitation process drew on the first four steps of DSM (*learn, winnow, cast, and discover*) [41], the initial two phases of UCD (*understanding context of use* and *specifying user requirements*) [42], and the first three stages of DCD (*preparation, knowledge elicitation, and analysis and representation*) [44]. These approaches were merged and operationalized into three stages: (1) precondition and preparation, (2) knowledge acquisition and characterization, and (3) analysis and representation, with subsequent design and evaluation phases planned for future work. DSM ensured methodological rigor and problem characterization through iterative domain expert engagement; UCD emphasized contextual inquiry and stakeholder needs; and DCD supported the analysis of complex cognitive processes in physiotherapy decision-making. Together, they provided a robust foundation for deriving clinically relevant, user-informed, and cognitively aligned design requirements. A detailed mapping of their contributions is presented in Table 1.

The main author (EW) conducted the work-flow observations and moderated the focus groups in German in March and April 2021. His researcher characteristics are the following: “gender: Male”, “experience: six years research experience in health informatics, main focus in physiotherapy and movement analysis projects”, “degree: M.Sc. in Computer Science”, “occupation: Research assistant”.

The ethics committee of Osnabrueck University of Applied Sciences approved the research project

(D-no: HSOS/2021/1/1, decision date: 17. March 2021). Prior to participation, all participants gave their consent to participate. Information about the study was given in oral forms.

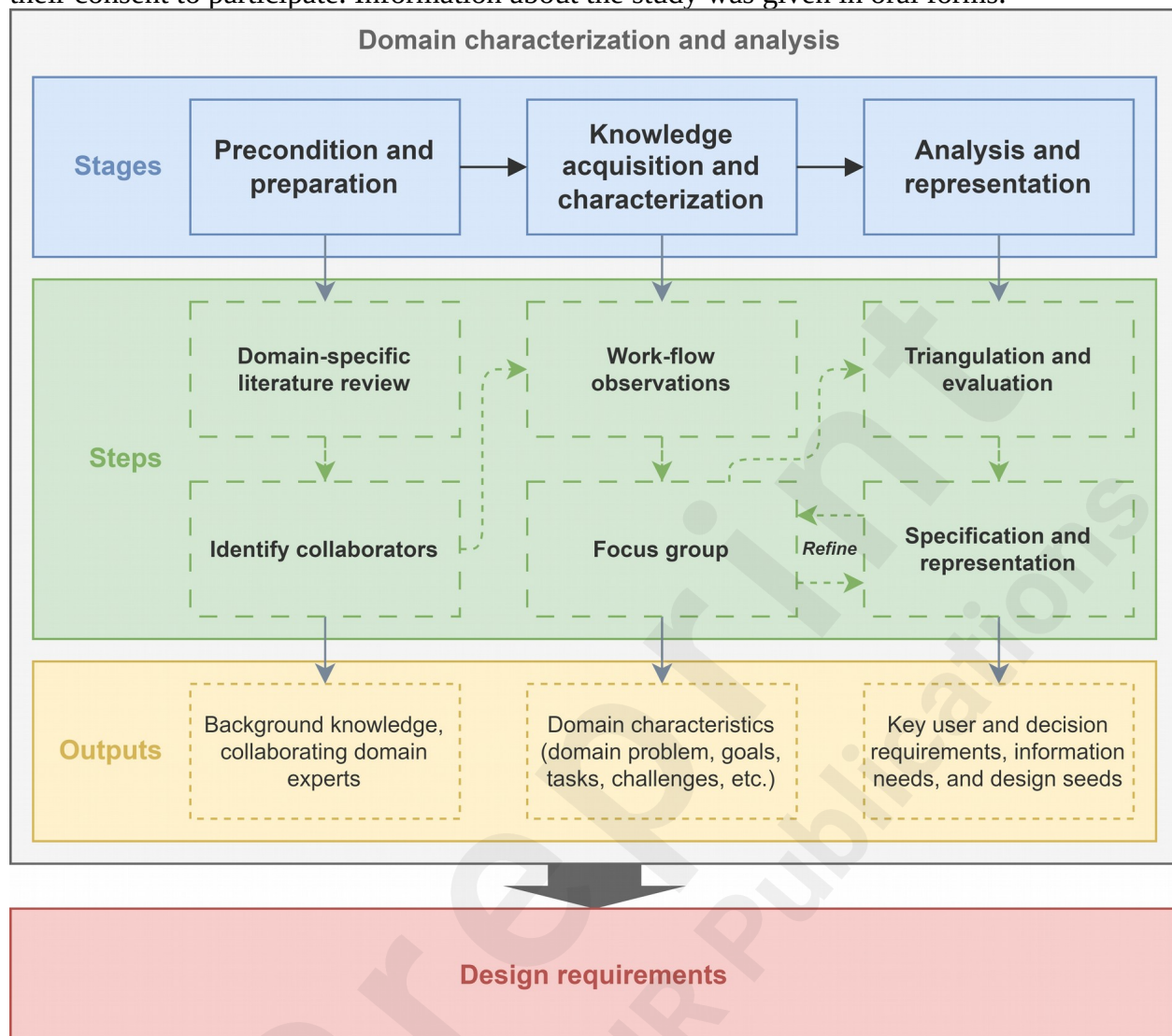


Figure 1. The domain characterization and analysis process comprised three stages with multiple steps and outputs, ultimately defining design requirements for an interactive physiotherapy dashboard.

Table 1. Detailed mapping of each method's contributions to domain characterization and analysis.

RESEARCH STAGE	DESIGN STUDY METHODOLOGY (DSM)	USER-CENTERED DESIGN (UCD)	DECISION-CENTERED DESIGN (DCD)
Precondition and preparation	- Domain understanding - Relevant terms and jargon - Identification of collaborators	Understanding user group characteristics and context of use	Identification of cognitively challenging activities from previous task descriptions
Knowledge acquisition and characterization	- Focus on real-world domain problem characterization - Domain expert engagement	- Participatory engagement through workflow observations and focus groups - Elicitation of user needs - Focus on user goals and task alignment	Identification of cognitive demands, critical cues, and information needs
Analysis and representation	- Iterative synthesis of findings into design seeds - Structured representation of design implications	- Specifying user requirements - Integration of usability concerns - Clarity and traceability of user needs to system design	- Specifying decision requirements - Integration of cognitive support needs in clinical workflow - Translation of decision-making

			needs into design recommendations
--	--	--	-----------------------------------

Precondition and preparation

Domain-specific literature review

Domain-specific literature from physiotherapy, clinical biomechanics, and movement analysis of musicians was reviewed to gather background information about the domain and user group characteristics and to become familiar with relevant terms and jargon (e.g., [6,8–11,13–15,17,19,21,23,29,31,46–57]). Previously articulated task descriptions, such as clinical reasoning and functional diagnostics, were examined to gain domain understanding and to initially identify cognitively complex components.

Identify collaborators

The INAPO, a specialized facility for treating neuromusculoskeletal disorders, served as a cooperation partner. INAPO has specialized in the treatment of musicians in close cooperation with the "Institute for Music" at Osnabrück University of Applied Sciences. Admitted patients receive tailored treatment and exercise programs. INAPO emphasizes staying updated with scientific progress in musicians' health and movement sciences, using modern therapy methods. As part of the *RefLabPerform* project, a CMA lab was established at INAPO, equipped with optoelectronic motion capture, surface electromyography sensors, and force plates. Requirements were gathered based on the CMA lab and INAPO's clinical practice needs.

Four physiotherapists (one male, three female) from INAPO and an expert for clinical reasoning and applied biomechanics from the University of Applied Sciences Osnabrück were selected face-to-face as domain experts for systematic collaboration during requirements elicitation. Purposive sampling ensured the inclusion of a representative sample of practicing physiotherapists with extensive experience in managing musicians with musculoskeletal problems.

Knowledge acquisition and characterization

Work-flow observations

We employed contextual inquiry to observe the workflow of physiotherapists managing musicians with musculoskeletal problems at INAPO prior to the focus group discussion. Contextual inquiry, a qualitative user research method, involves observing and interviewing potential users in their work environment as they perform actual tasks [58], i.e., watching them perform tasks while asking questions about their actions and thought processes. This method uncovers tacit knowledge, reveals detailed work practices, and provides reliable, relevant information about user needs and behaviors. The goal was to identify and gather domain experts' needs and preferences for a physiotherapist dashboard and CDS concerning their (cognitively challenging) tasks and daily data encounters. Additionally, we asked the experts about their thoughts on the integration of musician-specific CMAs into the diagnostic process and the application in clinical decision-making.

EW observed three physiotherapists experienced in managing musicians with musculoskeletal problems, previously selected for collaboration, during their daily work routines over one week. Each session lasted about two hours, allowing for detailed observation and discussion. Observations continued until thematic saturation was reached. Workflow diagrams were created from observation notes and presented at the focus group meeting to facilitate discussion on workflow processes.

Focus group

We conducted an online focus group [59] lasting approximately 270 minutes (4.5 hours), comprising

seven participants: the four collaborating domain experts, two computer scientists, and one user experience designer. Video and audio recordings were made using Zoom (Zoom Video Communications, Inc., USA). The focus group aimed to gain a deeper understanding of the domain, exploring the working environment, clinical procedures, user needs, and decision-making processes in musicians' physiotherapy, providing essential information for the tool's design. The primary goal was to establish a common understanding of the domain and address the following key discussion topics for the specific setting:

- Goals, skills, and barriers in musicians' physiotherapy
- Required collaborations, tools, and equipment
- Workflow structure and objectives of each step
- Information, tools, and activities per work step
- Motion analysis lab workflow and physiotherapist interaction

Given the lack of standardized procedures for focus group data collection and analysis, which depend on the research question and timeframe, we opted to organize the results into a mind map during the discussion to facilitate consensus-building. Following the focus group session, the research team held a debriefing session to review the discussions and identify key points.

Analysis and representation

Triangulation and evaluation

The qualitative data was triangulated and evaluated to determine how the tool can address the domain problem and user needs, and support decision-making. First, the insights from workflow observations and the focus group were organized and contextualized with domain-specific literature to understand and describe the domain characteristics. Further evaluation of the findings revealed key user needs, as well as cognitively challenging tasks, strategies, difficulties, and critical aspects in musicians' physiotherapy.

Specification and representation

Based on the prior findings, the solution's characteristics were specified. First, a workflow for integrating musician-specific CMA was established and visualized. Key user requirements, cognitive tasks, decision requirements, and associated information needs were then derived and formulated. Subsequently, design seeds to support decision-making were created. These findings were organized in tabular form.

In a second online focus group discussion, which lasted approximately 180 minutes (3 hours), the identified domain characteristics, specified user and decision requirements, and design ideas were revisited with the same group of experts and researchers. During this session, these elements were discussed in detail and refined based on their feedback.

Finally, incorporating knowledge and conditions from the theoretical background and domain, concrete design requirements were specified, including key features, technical prerequisites and decision support recommendations.

Results

Characteristics of the domain

To describe the domain, the characteristics were categorized under the following themes: domain problem; goals, skills and competences, work equipment, and barriers; and tasks, routines, and challenges.

Domain problem

The unresolved domain problem is integrating musician-specific CMA into musicians' physiotherapy and offering visual-interactive access to aggregated findings and treatment data for decision support. Musicians' physiotherapy, an integral component of "musicians' medicine", specializes in the assessment and treatment of neuromusculoskeletal disorders prevalent among musicians. This specialty employs standard physiotherapeutic tools along with musician-specific questionnaires and CMAs to enhance diagnostic precision and facilitate data-driven therapeutic decisions. Post-intervention, the collection of relevant patient questionnaires and repeated CMAs is crucial for effective therapy evaluation. However, an efficient technical solution for the comprehensive integration and analysis of clinical and biomechanical data tailored to musicians' physiotherapy remains absent. The primary beneficiaries of such a solution would be physiotherapists, with musicians gaining from improved, targeted therapies. Additionally, specialized physiotherapists or movement scientists trained in musician-specific CMAs, would benefit from enhanced integration of CMA into the therapeutic process.

Documentation, typically on paper, should be electronic for comprehensive evaluation. Integrating CMAs adds complexity, requiring standardized data processing and effective communication between physiotherapists and movement labs. Current software for biomechanical analysis is not user-friendly for physiotherapists, lacking advanced visualization, interactive data exploration, and contextualization of clinical and biomechanical data. A new solution is needed to simplify data analysis and visualization for therapists, with requirements evolving during implementation.

Goals, skills, competences, equipment, and barriers

Table 2 summarizes the goals, skills, competences, work equipment, and (potential) barriers cited by domain experts. The primary goal of physiotherapists is to provide high-quality patient care to enhance or maintain sensorimotor self-determination. This requires addressing the patient's main problems and goals efficiently to implement effective, targeted therapies. It is crucial to assess the effectiveness of therapeutic measures continuously, aligning interventions with the patient's condition and goals. Achieving these outcomes demands extensive skills and competences, particularly in CR, which is central to effective therapy [57].

Domain experts highlight the importance of a solid background in (patho-)anatomy, physiology, normative and comparative values, and evidence-based assessments, tests, and interventions. Clinical experience is also vital for developing communication and manual skills, refining techniques, interpreting tests, and recognizing clinical patterns. Further general requirements for physiotherapists are outlined in the literature (cf. [57]). Domain experts identified several tools used in therapy, including musician-specific patient questionnaires, body tables, numerical rating scales, goniometers, and algometers.

Physiotherapists face several barriers that can impede therapeutic objectives, including insufficient background knowledge, limited clinical experience, and shifts in knowledge due to ongoing education. Patient-related barriers include compliance issues and unrealistic expectations. Additionally, legal, or institutional barriers, such as limited examination and treatment time, and insufficient financial, technical, or spatial resources, also pose significant challenges.

Table 2. Domain-specific goals, skills and competences, work equipment, and barriers.

GOALS	SKILLS AND COMPETENCIES	EQUIPMENT	BARRIERS
- Enhancing or maintaining sensorimotor self-determination - Improving the main problem	<i>Background knowledge:</i> - Patho-anatomy and physiology (clinical patterns, clinical picture, musician-specific traits) - Reference values (standard, individual, musician-specific)	- Patient questionnaires - Diagnostic questionnaires - Body tables - Numerical rating	<i>Physiotherapist:</i> - Lack of background knowledge - Lack of clinical experience - Shift in knowledge and beliefs, e.g., through further education and training - Premature judgments

Addressing patient goals	- Scientific evidence for assessments, tests, interventions <i>Clinical experience:</i> - Communication skills - Manual skills - Recognizing clinical patterns - Techniques - Test interpretation	- scale - Measuring instruments (e.g., goniometer, algometer)	<i>Patient:</i> - Compliance - Background (cognitive, social, educational) - Negative experiences - Unreasonable expectations <i>General conditions:</i> - Legal: Limited time, lack of resources (e.g., financial) - Institutional: Limited time, lack of resources (e.g., premises, measuring instruments), availability of qualified therapists
--	--	--	--

Tasks, routines, and challenges

The cyclical CR process consists of eight main phases: Looking, Collecting, Processing, Deciding, Planning, Acting, Evaluating, and Reflecting [12]. These phases are interrelated and often overlap. The technical solution should explicitly assist the therapist in five of these steps:

- Collecting:* Recording all subjective and objective findings
- Processing:* Analyzing and interpreting the findings
- Deciding:* Assessing the findings for diagnosis and planning
- Evaluating:* Assessing the intervention(s) based on the repeat findings
- Reflecting:* Assessment of therapy effectiveness

The diagnostic process in physiotherapy involves examination, evaluation, and reassessment of findings and therapy measures under significant time pressure. Therapists must extract relevant information to make accurate treatment decisions, recognizing anomalies and changes in data [60].

Work-flow observations and focus group discussion provided a deeper understanding into the therapeutic and diagnostic processes in musicians' physiotherapy. Before the first consultation, patients complete musician- and problem-specific questionnaires, and the results guide the subjective examination, including background information and symptoms. This information helps generate diagnostic hypotheses tested during a physical examination, often using tools like goniometers. The results confirm or reject these hypotheses, leading to a physiotherapeutic diagnosis and a customized treatment plan. Treatment effectiveness is evaluated regularly, with reassessments before each follow-up to adjust or stop treatment as needed.

Specification and representation

The findings from the prior domain characterization were further examined and discussed with the domain experts. This process aimed to address the integration of musician-specific CMA into physiotherapy, identify user requirements, and determine key cognitive tasks and decision requirements.

Integrating musician-specific CMA into physiotherapy

Based on the domain experts' input, the integration of musician-specific CMA into physiotherapy was designed. It is crucial to incorporate CMA efficiently, providing valuable information on a musician's dysfunction. The timing, execution, and result delivery are critical for high clinical benefit and rapid transfer from the movement analysis lab to the therapist. The CMA aims to test diagnostic hypotheses and evaluate therapeutic measures' effectiveness. Biomechanical data should be classified and interpreted within the clinical context, structured as additional findings, and made available to therapists.

Figure 2 proposes integrating CMA into the assessment process alongside the physical examination. Clinical reasoning underpins CMA use, starting with a clear question based on a working hypothesis, guiding the selection of muscles, starting positions, testing types, and biomechanical characteristics.

This procedure is referred to as a movement analysis protocol based on Kontaxis et al. [61].

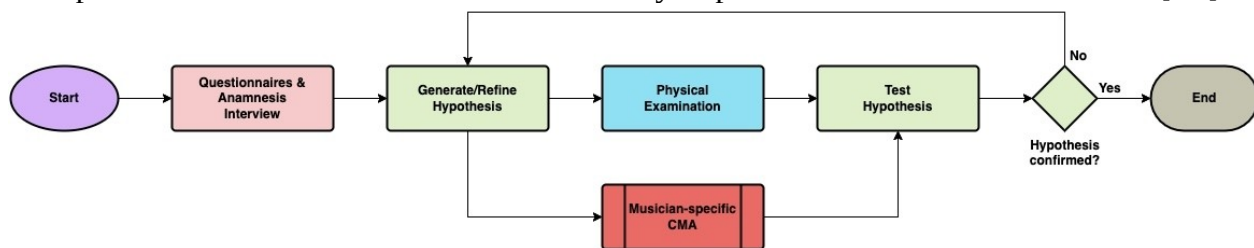


Figure 2. The revised diagnostic process integrates CMA as a complementary tool alongside physical examination (own illustration). It begins with musician/problem-specific questionnaires and anamnesis, followed by the generation of diagnostic hypotheses. A physical examination is then conducted to test these hypotheses. Simultaneously, a musician-specific CMA, guided by the hypotheses and a predefined movement analysis protocol, provides objective validation. If hypotheses require refinement or new ones emerge, additional physical exams and/or CMA assessments are performed until the final hypotheses are confirmed.

In addition to utilizing CMA for functional diagnostics during the initial assessment, a subsequent CMA is conducted post-treatment, as depicted in Figure 3. This allows for a pre-post comparison to evaluate the effectiveness of the treatment interventions.

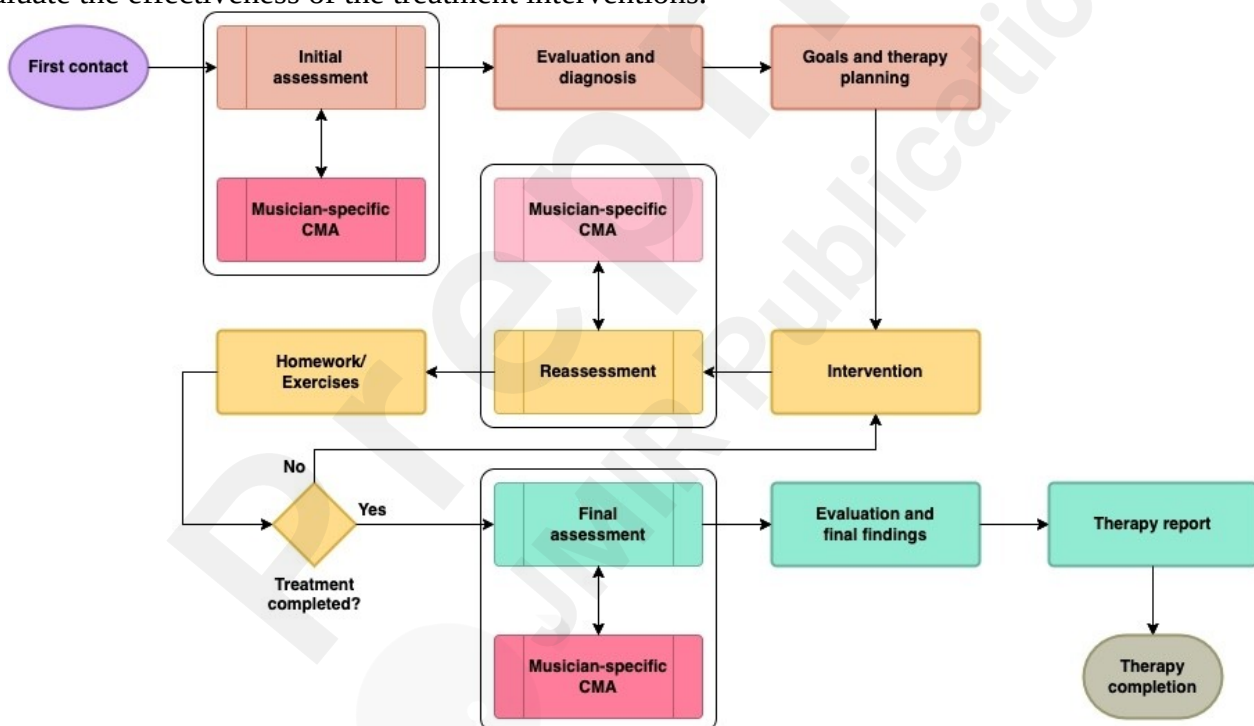


Figure 3. The modified clinical procedure integrates CMA for pre-, intra-, and post-treatment assessment (own illustration). Following the initial contact, an assessment is conducted, leading to findings evaluation, final diagnosis, goal setting, and therapy planning. After intervention, a reassessment is performed, and patient homework exercises are provided. If treatment continues, further interventions and reassessments follow; if completed, a final assessment, therapy evaluation, and report are conducted before concluding therapy.

User requirements

Contextual analysis, informed by the domain-specific literature, workflow observations, and focus groups, revealed user needs concerning the solution's characteristics. In total, 21 user stories were defined based on these needs, reflecting the users' expectations of the physiotherapist dashboard's

functionality [62]. These user stories pertain to clinical findings and treatment documentation, CMA, analysis and evaluation, and reporting. The full list of user requirements is available in Multimedia Appendix 1.

Cognitive tasks and decision requirements

Cognitively challenging activities were identified, such as diagnostics, treatment planning, and therapy evaluation, informed by task descriptions from literature and the findings from knowledge acquisition and characterization. For each activity, we identified critical cues used by experts, potential errors, and procedures to meet cognitive demands. Physiotherapists generate and test hypotheses by interviewing patients and conducting or commissioning examinations, continuously integrating, and interpreting the information. Each activity is a cognitively challenging demand, requiring decisions on what information to gather and when to stop, as well as determining the next steps in treatment.

Finally, seven key cognitive tasks were identified: (1) querying specific patient questionnaires, (2) subjective examination of the patient, (3) testing diagnostic hypotheses, (4) consolidating and evaluating the information relevant to therapy, (5) planning the adapted therapy, (6) treating a patient's specific problem in an iterative approach, and (7) evaluating the therapy results. The final list of key cognitive tasks and the associated strategies, (potential) errors or difficulties, and critical hints of the domain experts can be found in Multimedia Appendix 2.

In coordination with the domain experts, key decision requirements were extracted from these activities, focusing on planning, and assessing examinations and treatments while considering musician-specific CMA. Information needs for each decision were defined, specifying the clinical information needed. This approach led to design recommendations for decision support, offering early HCI concepts for organizing and visualizing information.

Five key decision requirements were identified incorporating musician-specific CMA in the context of physiotherapeutic diagnostics: (1) plan functional diagnostic examination, (2) assess CMA findings, (3) prepare overall finding and, if necessary, report of findings, (4) compare results of reassessments and evaluate treatment effectiveness and (5) evaluate therapy results and success. Based on the key decision requirements and associated information needs, a total of 49 design seeds were identified. The final list can be found in Multimedia Appendix 3.

Physiotherapists must decide if, when, and how to perform a CMA for a patient, considering basic patient information, contributing factors, symptoms, previous CMA parameters, and time and number of previous treatments. They must quickly evaluate findings to plan next steps, gaining an overview of the patient's problem, identifying patterns, and confirming diagnostic hypotheses to formulate a physiotherapy diagnosis. They must determine which data are therapy-relevant to create an overall finding or report.

Throughout treatment, physiotherapists continuously assess findings and treatment effectiveness, deciding if measures positively impact the patient's problem or need adjustment. They review therapy-relevant information before and after treatments to identify trends and changes. They reflect on therapy outcomes and their actions, assessing whether therapy was successful and identifying key factors. They monitor achievement of therapy and patient goals using data from baseline and follow-up findings, treatment results, and relevant questionnaires, including post-intervention CMA results.

Design requirements

The *Domain Characterization and Analysis* informed concrete design requirements for a physiotherapist dashboard, specifying key features and CDS recommendations based on user needs for decision support. The use case defined technical prerequisites for implementation.

Key features

Based on the insights gained, we identified six key features (K_F) that form the basic pillars of the tool and must be fulfilled during design and implementation:

- KF1.** *Provision of biomechanical findings:* Musician-specific CMAs should be efficiently integrated into therapy to give physiotherapists valuable insights into a patient's dysfunction. Biomechanical data must be processed, modeled, and stored to produce a report with relevant characteristics for further analysis.
- KF2.** *Integration of heterogeneous data types and sources:* For a holistic inspection and assessment of all available information from the subjective and objective examinations of a patient's problem, it is necessary to combine different types of data from different data sources. This includes clinical findings and treatment data from physiotherapy documentation, results from online questionnaires and biomechanical findings data from movement analysis.
- KF3.** *Adaptive overview:* A simplified aggregated overview is essential for quick and clear inspection and monitoring of patient-related information. This should include basic therapy data, recent findings, and treatments, as well as relevant individual patient details. Information should be adaptive and patient-specific, allowing physiotherapists to manually add or remove data. Detailed views should be accessible via a drill-down function.
- KF4.** *Adequate visual representations and interaction techniques:* Efficient visualizations, such as lists, tables, diagrams, and illustrations, should be chosen to aid physiotherapists in effective decision-making. Therapists should be able to manually arrange and configure these elements and use familiar interaction techniques like drag-and-drop, sorting, searching, and filtering.
- KF5.** *Efficient visual-interactive analysis of findings and treatment results:* Physiotherapists need an efficient solution for interactive visual analysis of findings and treatment results to identify abnormalities, trends, and patterns in clinical and biomechanical data. Established visual analytics methods will be used to explore and compare multivariate and time-oriented data.
- KF6.** *Preparation and export of findings and analysis results:* Physiotherapists should be able to summarize and export therapy findings as a report for discussion with colleagues and patients, or for continued treatment elsewhere. The report should be presented in a clear, customizable format.

CDS design recommendations

The user needs and design seeds addressing decision requirements formed the basis for specifying concrete CDS design recommendations (D_R) (see Table 3).

For planning musician-based diagnostics, it is helpful to have a note indicating if such an examination is possible for the patient (D_{R1}). CDS should remind the physiotherapist to conduct pre- and post-interventional exams if possible (D_{R2}). Additionally, suggested configuration parameters should be provided when creating an examination order to save time (D_{R3}).

To efficiently query and inspect findings and treatment results, essential data should be preselected for the overview (D_{R4}). Information should be summarized in aggregated elements and presented in suitable display formats (D_{R5}). Relevant therapy events should be shown on a timeline (D_{R6}). Additionally, visual cues should highlight significant data changes to reduce cognitive load and speed up decision-making (D_{R7}).

For interpreting findings, integrating normative and comparative values is desirable (D_{R8}). Therapists should be able to create interactive annotations (D_{R9}), marking specific data values or time intervals. To support diagnosis, findings and annotations should be linked to diagnostic hypotheses, showing which data support or refute them (D_{R10}). Additionally, marking applicable or inapplicable hypotheses interactively should be possible (D_{R11}).

For therapy evaluation, directly comparing baseline and final findings is essential (D_{R12}). An interactive review of patient and therapy goals helps determine therapy success, requiring target

parameters for goal achievement (D_{R13}). Preselecting relevant entries and suitable presentation forms aids in report preparation (D_{R14}).

Table 3. Overview of the clinical decision support design recommendations (D_R).

CATEGORY	DECISION SUPPORT RECOMMENDATION	
Planning musician-specific examinations for functional diagnostics	D_{R1}	Indicate if musician-specific examinations are possible for the patient.
	D_{R2}	Remind physiotherapists to conduct pre- and post-interventional examinations.
	D_{R3}	Provide suggested configuration parameters for examination orders to save time.
Query and inspection of diagnostic findings and treatment results	D_{R4}	Preselect essential data for efficient querying and inspection.
	D_{R5}	Summarize information in aggregated elements and suitable display formats.
	D_{R6}	Map relevant events on a timeline.
	D_{R7}	Use visual cues to highlight abnormal data or significant changes.
Analysis and interpretation of the findings data	D_{R8}	Integrate normative and comparative values for interpreting findings.
	D_{R9}	Allow interactive annotations for specific data values or time intervals.
	D_{R10}	Link findings and annotations to working hypotheses.
	D_{R11}	Mark working hypotheses as applicable or not with appropriate presentation.
Therapy evaluation and reporting	D_{R12}	Enable direct comparison of baseline and final findings for therapy evaluation.
	D_{R13}	Facilitate an interactive review of patient and therapy goals, with target parameters for goal achievement.
	D_{R14}	Preselect relevant entries and use appropriate presentation formats for report preparation.

Technical prerequisites

Technical prerequisites (T_P) must be established to enable the physiotherapist dashboard (see Table 4). The tool should allow physiotherapists to access patient data and case history (T_{P1}), including anamnesis, physical exams, and treatment records (T_{P2}). Patients must complete validated musician- and problem-related questionnaires online, with results integrated into the findings overview (T_{P3}). Biomechanical data from musician-specific CMAs should be available as findings (T_{P4}).

Functional diagnostics occur in a CMA lab within a physiotherapy practice, staffed by specialists. Physiotherapists must submit *electronic exam orders* with relevant CMA details (e.g., patient ID, instrument group, and symptoms) (T_{P5}). The lab requires an *order management system* to track requests and update CMA status (T_{P6}) and a *data management system* for recorded measurements (T_{P7}). Standardized, musician-specific CMA protocols should be implemented (T_{P8}), integrating existing measurement tools and software (T_{P9}). Data processing and calculations should be largely automated (T_{P10}), with results provided as biomechanical findings (T_{P11}).

Table 4. Overview of the technical prerequisites (T_P) to enable the physiotherapist dashboard.

CATEGORY	TECHNICAL PREREQUISITES (T_R)	
Integration of therapy-related patient data	T_{P1}	Integration of patient and case data
	T_{P2}	Integration of clinical findings and progress data
	T_{P3}	Integration of the online questionnaire results
	T_{P4}	Integration of the biomechanical findings data
Laboratory system	T_{P5}	Electronic order entry

T _{P6}	Laboratory order management
T _{P7}	Laboratory data management
T _{P8}	Standardized motion analysis protocols
T _{P9}	Integration of existing biomechanical measuring instruments/systems and analysis software
T _{P10}	(Largely) automated processing and calculation of relevant features
T _{P11}	Providing data from CMA as biomechanical findings

Discussion

Principal findings

We proposed and applied a novel HFE process model to inform the design of a physiotherapist dashboard with CDS for CMA of musicians with musculoskeletal problems, using methods, and addressing aspects from DSM, UCD, and DCD. Following this model, we first identified and thoroughly described the characteristics of the domain and problem area. We explored user needs, cognitively challenging tasks, information needs, and decision-making challenges faced by physiotherapists managing musicians with musculoskeletal conditions. We then proposed design seeds for CDS, translating user and decision requirements into concrete design requirements, including key features, technical prerequisites, and recommendations for decision support.

Key features include efficient integration of biomechanical data, combining heterogeneous data types, and providing adaptive overviews for quick data inspection. The tool should present patient data in a suitable form and facilitate interactive visual analyses using familiar techniques like filtering, highlighting, and annotating. Summarizing and exporting findings for communication are also essential. User and decision requirements led to specific decision-support recommendations: CDS should indicate if musician-specific diagnostics are possible, remind physiotherapists of physical exams, suggest efficient configuration parameters, preselect essential data, highlight significant changes, integrate normative values, support interactive annotations, compare baseline and final findings, and provide tools for reviewing patient goals and preparing reports. To enable the tool technical prerequisites must be met: include access to patient data (anamnesis, physical exams, treatments, and problem- or musician-related questionnaires), biomechanical data from musician-specific CMAs, support for electronic diagnostic orders, and management of these orders and CMA statuses. The tool should use standardized protocols, integrate with existing tools, and automate data processing to present biomechanical findings.

Additionally, our study contributes to the existing literature by detailing a methodology for requirements elicitation, comprehensively describing the domain of musicians' physiotherapy, and identifying requirements for the successful use of the tool. Our findings support previous research indicating that HFE is crucial for designing CDS technologies [34,35], emphasizing aspects such as speed, efficiency, user needs anticipation, workflow integration, meaningful alerts, consistency, logical grouping, interface design, and design simplicity [37–40].

Limitations

This study is in the early stages of design, focusing on establishing a structured foundation for the tool's design and domain-specific clinical workflows, relying primarily on qualitative methods like workflow observations and focus group discussions. While the findings provided in-depth qualitative insights from a small group of domain experts, generalizability is limited, and broader validation is needed. To address this, we plan to conduct a Delphi study involving a larger and more diverse panel of physiotherapists, movement scientists, and other relevant stakeholders [63]. This structured, iterative process will facilitate expert consensus on the tool's design requirements, ensuring their

robustness and applicability across various physiotherapy contexts. The Delphi study will also help refine the identified requirements based on collective expert feedback, enhancing the tool's validity before further prototyping, usability testing, and implementation in clinical practice.

At this stage, no functional prototype exists and technical features or implementation details, such as specific visualizations, interaction methods, and decision logic, were not addressed. These aspects will be defined and iteratively refined during future stages of prototyping and evaluation. Furthermore, quantitative evaluation of metrics such as diagnostic accuracy, efficiency, or patient outcomes is not yet feasible. Future work will involve the development of a prototype, followed by iterative usability testing and structured evaluations. These evaluations will incorporate quantitative measures—such as time-to-decision, task completion rates, diagnostic decision support effectiveness, efficiency gains, and user satisfaction scores—to assess the tool's impact and clinical utility in real-world physiotherapy settings.

In addition, artificial intelligence (AI)-based CDS features were overlooked. Integrating machine learning and predictive analytics could significantly enhance precision and relevance [64]. In future development stages, machine learning algorithms can be incorporated to support early diagnosis, pattern recognition, as well as personalized treatment planning and outcome prediction considering individual patient characteristics. For example, supervised learning models could be trained on annotated CMA data to automatically identify movement anomalies or classify injury risks [64]. Predictive analytics could also be used to forecast recovery progression based on patient-specific parameters such as movement patterns, therapy progress, and contextual factors (e.g., instrument type or workload) [65]. These enhancements would augment the therapist's decision-making with advanced data-driven insights, while maintaining transparency and clinician control. Overall, this highlights the tool's extensibility and long-term innovation potential.

Moreover, while the proposed CDS approach focuses on integrating CMA with gold-standard methods, AI-driven approaches like computer vision-based pose estimation (e.g., OpenPose [66]) should be explored. Sensorless systems could provide non-intrusive, real-time movement tracking, making assessments more accessible, especially in non-laboratory settings. AI pattern recognition could automate impairment classification and suggest diagnostic hypotheses, aiding physiotherapists and improving decision-making. It could also enable remote physiotherapy, allowing musicians to exercise at home with real-time feedback. However, challenges in accuracy, occlusion, and clinical validation must be addressed before full integration into physiotherapy workflows.

Opportunities and challenges

The integration of CMA into physiotherapy and incorporating clinical and biomechanical data with CDS within an interactive dashboard, presents both opportunities and challenges. Our study emphasizes the need to tailor CDS to real clinical environments and therapists' workflows. Ensuring these technologies are perceived as useful is crucial, as the balance between perceived benefits and implementation effort significantly affects adoption. Developing an interactive tool for supporting diagnosis and treatment of musculoskeletal disorders in musicians requires a multidisciplinary approach, combining health informatics, biomechanics, and clinical practice. Collaboration with domain experts ensures the tool meets practical needs. Requirements were elicited through problem-driven research, ensuring that real-world problems were addressed, as well as UCD and DCD approaches, considering user needs, cognitive demands, and decision requirements, aiming to enhance the usability and usefulness of the solution.

Most existing tools in physiotherapy focus on general clinical documentation [67] or basic measurement instruments like goniometers and numeric rating scales [18], with limited quantitative and objective significance. Advanced biomechanical analysis systems (e.g., Qualisys [68]) remain primarily research tools—technically complex and disconnected from everyday clinical decision-making, lacking user-friendliness, tailored visualizations, and integration with clinical reasoning.

CDS tools in physiotherapy are still emerging, with AI-based approaches showing promise for personalizing treatment and predicting patient-specific outcomes [69–71]. However, they lack integration of CMA into clinical workflows and provide limited support for context-specific decision-making, particularly for niche populations like musicians with PRMDs. Existing visualization tools support rehabilitation or monitoring but do not incorporate CMA data [72,73], and those that do focus on clinical gait analysis or specific disorders [74,75]. Currently, no tool integrates CMA data into the decision-making process for physiotherapists managing musicians with PRMDs.

An interactive tool based on the identified design requirements would fill this gap by directly integrating CMA into clinical workflows, aligning with physiotherapists' reasoning. It would enable interactive visualizations tailored to the needs of diagnosing and treating musicians with PRMDs, offering flexibility for different instruments and playing styles. Unlike existing tools, it bridges the gap between biomechanical analysis and clinical practice, providing musician-focused support and a platform for integrating advanced analytics to enhance diagnostic precision and longitudinal tracking. Such a system aims to integrate CMA into real-world physiotherapy workflows, providing context-aware support and decision facilitation across all therapy stages, particularly for underserved populations like performing artists.

The successful deployment of a future CDS tool will require addressing key technical and ethical challenges. Integration into existing healthcare IT systems involves overcoming data heterogeneity, ensuring interoperability, safeguarding data privacy, and achieving clinician adoption. Many institutions rely on proprietary electronic health records (EHRs) [76], complicating seamless data exchange. Standardized protocols such as HL7 and FHIR can help address interoperability [77], while compliance with regulations like GDPR will require robust encryption, anonymization when applicable, and role-based access controls. Diverse IT environments further necessitate system compatibility; a modular, cloud-based architecture could offer the flexibility and scalability needed for broad adoption [78]. Clinician adoption will depend on smooth integration into existing workflows, user-friendly interfaces, and comprehensive training [79].

Future work must standardize and integrate diverse data sources—such as motion capture outputs, clinical notes, and patient records—into a unified platform compatible with physiotherapy workflows. Ethical considerations are equally critical. The envisioned tool is designed to assist, not replace, physiotherapists by providing objective biomechanical data to enhance—not automate—clinical decision-making. The system will maintain clinician autonomy, ensure transparency and interpretability, and be developed in adherence to data protection regulations. Although risks related to automation or bias are minimal at this stage, they will remain important considerations in later development phases, particularly as data handling, user control, and AI components evolve. Finally, the evolving nature of clinical practices and data types presents ongoing challenges for maintaining a CDS tool's relevance. Continuous updates are needed to keep pace with advancements in clinical knowledge and technology, which can be resource intensive. Addressing these challenges in future research will enhance such a tool's usability, adaptability, and impact on clinical decision-making.

In conclusion, successful implementation of the physiotherapist dashboard with CDS based on musician-specific CMA depends on alignment with clinical workflows, ease of use, successful integration in existing IT infrastructure, maintaining data protection and clinician autonomy, and demonstrable benefits in diagnostic accuracy and treatment efficiency. Insights from this study provide a solid foundation for designing an interactive tool for physiotherapists, incorporating CMA for musicians with musculoskeletal demands, aiming to improve patient outcomes and support clinical decision-making. Iterative feedback from domain experts during design and development should ensure the tool addresses real-world problems, is validated through practical application, and is continuously refined based on user insights. The involvement of physiotherapists and movement scientists from initial design to validation is pivotal.

While this study focuses on the niche context of musicians with PRMDs, the identified design

requirements, domain-specific decision-making insights, and integration of CMA hold potential for broader application. The underlying framework and methodology can be adapted to other physiotherapy contexts that involve complex, movement-related diagnostic and therapeutic challenges—such as in athletes, dancers, or individuals with work-related repetitive strain or posture-related injuries. These populations similarly require tailored functional assessments and context-specific clinical decision support [80–83]. Modular, task-oriented design supports adaptation across these groups by enabling customization of movement analysis protocols, clinical decision parameters, and visualization formats to meet domain-specific needs. This enhances both the generalizability and scalability of the proposed framework. Future work may explore how the proposed process model and design requirements can be transferred and tailored to other physiotherapy contexts, extending the broader relevance and impact of this research beyond musicians.

Conclusion and future work

This work contributes to HFE, physiotherapy, CMA, and CDS for musicians with PRMDs by combining rigorous research methods with expert insights. The proposed process model helps stakeholders identify user needs and decision-making requirements at the point of care, while the design requirements lay the groundwork for developing a specialized interactive physiotherapist dashboard integrating CMA with CDS. This tool can enhance diagnostic accuracy and therapy effectiveness through interactive, visual data presentation, streamline workflows, and maintain clinical relevance. Ultimately, it aims to improve patient outcomes, reduce injury recurrence, and support musicians' long-term careers.

In the next phase, we plan to translate the design requirements into a functional prototype. To ensure practicality and effectiveness, we will conduct rigorous usability testing and evaluations with physiotherapists. This will involve iterative feedback loops through think-aloud protocols and task-based evaluations, ensuring that the tool aligns with clinical workflows and cognitive demands. Structured feedback will be used to refine interface features, data presentation, and interaction flows, providing empirical evidence of feasibility, usability, and alignment with the identified requirements. Future research should validate usability, decision support, and clinical effectiveness, explore advanced analytics, adapt to various CMA systems (e.g., sensorless tracking), and expand applications across diverse musicians, instruments, and therapeutic domains to enhance its impact.

Acknowledgements

The authors would like to thank Florian Avermann, Camilla Kapitza, Heike Schemmann, Sabrina Friehe, Dirk Möller, Johanne Weber, and Lars Dorenbusch for contributing their time and expertise. This work is part of the *RefLabPerform* project and was funded by the Federal Ministry of Education and Research (BMBF) under research grant 13FH113PX8.

Conflicts of Interest

None declared.

Authors' contributions

Eduard Wolf conceptualized the study, recruited participants, collected, and analyzed data, and wrote the manuscript. Prof. Dr. Karsten Morisse contributed to the study's conceptualization and reviewed the final manuscript, while Prof. Dr. Sven Meister reviewed and finalized it.

Multimedia Appendix 1: User requirements formulated as user stories based on user needs for decision support

CATEGORY	USER REQUIREMENT	
Clinical findings and treatment documentation	U _{R1}	As a <i>physiotherapist</i> , I want to be able to view the outcomes of instrument- and problem-specific online questionnaires, so that I can check a patient's subjective state of health.
	U _{R2}	As a <i>physiotherapist</i> , I want to be able to view the outcomes of the medical history, so that I can check a patient's subjective self-assessment.
	U _{R3}	As a <i>physiotherapist</i> , I want to be able to view the outcomes of the physical examination, so that I can check the objective information on a patient's problems.
	U _{R4}	As a <i>physiotherapist</i> , I want to be able to view the interventions carried out, so that I can follow the course of treatment.
	U _{R5}	As a <i>physiotherapist</i> , I want to be able to view the therapy and patient goals, so that I can check these after the treatment has been completed.
Clinical movement analysis	U _{R6}	As a <i>physiotherapist</i> , I want to be able to order a standardized and musician-specific CMA, so that I can obtain reliable and objective information about an instrumentalist's playing movement.
	U _{R7}	As a <i>physiotherapist</i> , I want to be able to set examination parameters based working hypotheses, so that I can target the examination and confirm or reject the hypotheses.
	U _{R8}	As a <i>physiotherapist</i> , I want to be able to view the status of an instrumentalist's CMA, so that I can check the progress.
	U _{R9}	As a <i>physiotherapist</i> , I want to be able to retrieve relevant outcomes of an instrumentalist's CMA, so that I can review the biomechanical data on an instrumentalist's playing movement.
	U _{R10}	As a <i>physiotherapist</i> , I want to be able to view biomechanical findings in a temporally aligned way, so that I can inspect the data from different measuring systems in a in a holistic way.

	U R 11 As a <i>physiotherapist</i>, I want to be able to view activities from the CMA in a temporally aligned way, so that I can compare intra-individual findings of different measurement times.
	U R 1 2 As a <i>physiotherapist</i>, I want to be able to order additional standardized and musician-specific CMA, so that I can investigate intervention-related changes.
Analysis and evaluation	U R 1 3 As a <i>physiotherapist</i>, I want to be able to obtain a quick overview of all therapy events, so that I can efficiently understand the entire course of therapy for a patient.
	U R 1 4 As a <i>physiotherapist</i>, I want to be able to obtain a quick overview of all patient-related findings, so that I can check the current state of health of a patient.
	U R 1 5 As a <i>physiotherapist</i>, I want to be able to have the patient-related findings and treatment results represented in such a way that I can assess them efficiently.
	U R 1 6 As a <i>physiotherapist</i>, I want to analyze the findings in detail, so that I can arrive at a comprehensive understanding of a patient's problem.
	U R 1 7 As a <i>physiotherapist</i>, I want to confirm, adapt, or reject the current (working) hypotheses based on the findings, so that I can arrive at a physiotherapeutic diagnosis of a patient's problem.
	U R 1 8 As a <i>physiotherapist</i>, I want to extract the most important information, so that I can summarize it into an overall finding.
	U R 1 9 As a <i>physiotherapist</i>, I want to compare the final finding with the basic finding, so that I can finally check the success and effect of the therapy.
Reporting	U R 2 0 As a <i>physiotherapist</i>, I want to be able to create a report with the relevant information, so that I can enable the patient to continue treatment elsewhere.

	U R 2 1 As a <i>physiotherapist</i>, I want to be able to create a therapy report, so that I can summarize the progress and therapy results of a patient and, if necessary, to send it to a physician.
--	---

Multimedia Appendix 2: Cognitive tasks and associated strategies, (potential) errors or difficulties, and critical hints

COGNITIVE TASK	STRATEGY	ERROR/DIFFICULTY	CRITICAL HINTS
1. Querying specific patient questionnaires	- Physiotherapist asks for the patient's self-assessment using specific questionnaires. - Patient responds to the questionnaire items.	Patient provides incomplete or untruthful answers.	- Psychosocial factors - Musician-specific factors - Dysfunction-dependent factors - Pain mechanism and localization - Total and sub-scores
1.1 Deciding which questionnaires to give to the patient	Physiotherapist selects questionnaires based on patient information and the specific problem.	Physiotherapist lacks ability in selecting questionnaires.	- Patient information - Symptoms of the patient
1.2 Interpreting the questionnaire results	- Physiotherapist reviews and interprets questionnaire results. - Physiotherapist integrates findings into the subjective examination.	Physiotherapist lacks ability in assessing questionnaires.	Diagnostic significance of the information
2. Subjective examination of the patient	- Physiotherapist conducts an anamnesis interview about the patient's symptoms, medical history, and background. - Physiotherapist records and interprets the information to generate diagnostic hypotheses.	- Physiotherapist lacks ability in conducting history interviews. - Communicative difficulties between physiotherapist and patient. - Patient lacks compliance.	- Relevant/conspicuous information from the patient questionnaires - Main problem of the patient - Symptoms and pain - Symptom/pain localization - Symptom behavior/24h behavior - Short and long-term history - Previous and secondary diseases - Previous therapies - Contributing factors
2.1 Deciding which questions to ask the patient	Physiotherapist inquiries about alarming symptoms to rule out serious diagnoses.	Physiotherapist asks too few or avoids targeted diagnostic questions.	- Symptoms and pain of the patient - Red/yellow flags
2.2 Interpreting the information obtained	Physiotherapist interprets information based on clinical patterns.	- Physiotherapist lacks knowledge in risk factors and clinical patterns. - Physiotherapist rejects information that doesn't fit the clinical pattern.	- Diagnostic significance of the information - Clinical patterns/disease patterns
2.3 Deciding when to stop eliciting information	Physiotherapist stops the anamnesis interview once a satisfactory explanation is found.	Physiotherapist forms opinions too early.	- Diagnostic significance of the information - Clinical patterns/disease patterns
2.4 Generating diagnostic hypotheses	Physiotherapist generates diagnostic hypotheses early, based on questionnaire results and subjective findings.	Physiotherapist focuses too much on one hypothesis.	Relevant/conspicuous information from the patient questionnaires and the subjective examination
3. Testing diagnostic	Physiotherapist tests hypotheses by examining	Physiotherapist struggles to integrate new,	Diagnostic hypotheses

COGNITIVE TASK		STRATEGY	ERROR/DIFFICULTY	CRITICAL HINTS
hypotheses		relevant structures and functions.	- inconsistent information. - Patient lacks compliance.	- Patient information - Patient symptoms and pain - Physical and functional examination - Diagnostic tests
3.1	Deciding whether and which clinical examinations are to be carried out/requested	Physiotherapist conducts clinical exams, uses diagnostic tests, trial treatments, and requests further tests if needed.	- Physiotherapist lacks ability in selecting/performing tests. - Physiotherapist conducts inadequate clinical examinations.	- Diagnostic hypotheses - Symptoms and pain of the patient
3.2	Interpreting the information obtained	Physiotherapist interprets information according to the working hypothesis.	- Physiotherapist lacks experience in interpreting results. - Physiotherapist rejects information inconsistent with the leading working hypothesis.	- Diagnostic hypotheses - Diagnostic significance of the information
3.3	Deciding when to stop eliciting information	Physiotherapist stops the clinical exam once hypotheses are confirmed, and alternatives checked.	Physiotherapist conducts too few or inappropriate tests or forms opinions too early.	- Diagnostic hypotheses - Diagnostic significance of the information
4.	Consolidating and evaluating the information relevant to therapy	Physiotherapist assesses questionnaire and exam results to form an overall picture.	Physiotherapist lacks experience in interpreting information.	- Diagnostic hypotheses - Diagnostic significance of the information
4.1	Formulating the physiotherapeutic diagnosis	Physiotherapist formulates a diagnosis based on therapy-relevant information and confirmed hypotheses.	- Physiotherapist lacks ability in choosing the physiotherapeutic diagnosis. - Physiotherapist misdiagnoses due to incorrect information or hypotheses.	- Therapy-relevant information - Appropriate diagnostic hypotheses
4.2	Creating a report of findings	Physiotherapist compiles therapy-relevant information into a findings report.	Physiotherapist chooses non-therapeutic information.	- Therapy-relevant information - Physiotherapeutic diagnosis
5.	Planning the adapted therapy	Physiotherapist plans customized therapy, defining goals with the patient and creating a treatment plan.	Inappropriate management due to misdiagnosis or insufficient knowledge.	- Physiotherapeutic diagnosis - Therapy-relevant information
5.1	Defining therapy goals	Physiotherapist asks about patient goals and defines therapy goals together.	Inappropriate treatment goals due to misdiagnosis or patient goals.	- Physiotherapeutic diagnosis - Therapy-relevant information - Patient goals
5.2	Creating a treatment plan	Physiotherapist develops an initial treatment plan using evidence-based interventions and clinical guidelines.	Physiotherapist lacks knowledge of evidence-based interventions and guidelines.	- Physiotherapeutic diagnosis - Therapy goals - Evidence-based interventions - Clinical guidelines
6.	Treating a patient's specific problem (<i>iterative approach</i>)	Physiotherapist plans further treatment based on findings, diagnosis, and therapy goals.	Inappropriate management due to misdiagnosis or insufficient knowledge.	- Physiotherapeutic diagnosis - Therapy goals - Therapy-relevant information from basic findings and repeat findings
6.1	Deciding whether and which clinical examinations are to	Physiotherapist reassesses therapy-relevant information using the same diagnostic tests.	Physiotherapist lacks ability in selecting or performing tests.	- Current and past examinations - Relevant diagnostic tests

COGNITIVE TASK	STRATEGY	ERROR/DIFFICULTY	CRITICAL HINTS
be carried out/repeated		Physiotherapist performs inadequate reassessments.	
6.2 Interpreting the information obtained	Physiotherapist compares re-evaluation results with initial findings to determine long-term treatment effects.	- Physiotherapist lacks experience in interpreting test results and treatment effects. - Physiotherapist rejects information inconsistent with diagnosis or treatment plan.	- Results of the relevant diagnostic tests from the basic findings - Long-term effect of the treatment
6.3 Deciding which body structures to treat	Physiotherapist screens affected and possible related structures.	Physiotherapist lacks ability in screening or trial treatments.	- Symptoms and pain of the patient - Abnormal body structures
6.4 Deciding which interventions to carry out	Physiotherapist implements evidence-based interventions following clinical guidelines.	Physiotherapist lacks knowledge of evidence-based interventions and clinical guidelines.	- Abnormal body structures - Evidence-based interventions - Clinical guidelines
6.5 Deciding whether to adapt the treatment	Physiotherapist checks short-term treatment effects and adjusts if needed.	Physiotherapist lacks experience interpreting treatment results.	Short-term effect of the treatment
6.6 Deciding whether to stop treatment	Physiotherapist checks long-term treatment effects and therapy goals; stops treatment if goals are achieved.	Physiotherapist lacks experience interpreting treatment results.	- Long-term effect of the treatment - Therapy goals
7. Evaluating the therapy results	Physiotherapist compares current condition with pre-treatment condition and identifies influencing factors.	Physiotherapist lacks experience to interpret therapy outcomes or self-reflect.	- Physiotherapeutic diagnosis - Course of treatment - Pre-post comparison of relevant information
7.1 Deciding which patient questionnaires and diagnostic tests to repeat	Physiotherapist conducts a final reassessment using the same questionnaires and tests.	- Patient provides incomplete or untruthful answers. - Physiotherapist lacks ability in selecting or performing tests. - Physiotherapist conducts an inadequate final assessment.	- Relevant patient questionnaires - Relevant examinations from the survey
7.2 Deciding whether the therapy was successful and effective	Physiotherapist compares current and original information to check if therapy objectives and patient goals are achieved.	- Physiotherapist lacks ability in assessing questionnaires and calculating scores. - Physiotherapist lacks experience interpreting test results. - Physiotherapist rejects information that doesn't meet expectations.	- Relevant information from the patient questionnaires and the subjective and clinical examinations - Patient and therapy goals
7.3 Checking patient satisfaction	Physiotherapist asks about patient satisfaction with therapy and condition.	Patient has unreasonable expectations about therapy results.	- Patient details - Patient goals

Multimedia Appendix 3: Key decision requirements, associated information needs and design seeds

DECISION REQUIREMENT (DR)		INFORMATION NEEDS	DESIGN SEEDS (S)	
D R 1	Plan functional diagnostic examination (Deciding whether and how an CMA is to be carried out)			
	D R 1-1	Decide whether and which examination is requested	- Patient information - Contributing factors - Symptom areas of the patient - Previous examination parameters	S Note if musician-specific CMA is possible Suggestion of examination parameters
	D R 1-2	Decide when an examination is requested	- Number and timing of treatment units	S Note on pre-interventional examination Note on post-interventional examination
D R 2	Assess findings (Deciding how to interpret the results of the findings and how to proceed further)			
	D R 2-1	Gain an overview of a patient's problems	- Results of the respective individual findings • Questionnaires • Anamnesis • Physical examination • Functional examination - Possible comparative and reference values	S Presenting essential information in an aggregated and organized view Organize the information in lists, tables, charts, and figures Provide an interactive "drill down" function to view details of an entry Provide adequate displays to enable efficient inspection of features Provide more configurable displays to choose an appropriate presentation of the features

DECISION REQUIREMENT (DR)		INFORMATION NEEDS	DESIGN SEEDS (S)
D R 2- 2	Identify dysfunctional movement patterns and postures specific to different instruments	- See above	2 - 4 S 2 - 5 S Use of time-based displays to show time-dependent data over time 2 Use of comparative displays to enable comparison of data and characteristics - Use visual cues to draw attention to important and salient data and information 6 Integrating and presenting comparative and reference values S 2 Providing tools and displays to select appropriate forms of presentation of different characteristics - 7 Providing tools to investigate relationships between different characteristics S 2 Providing an interactive function to mark/highlight relevant entries and characteristics - 8 S 2 - 9 S 2 - 1 0 S 2 - 1 1 S 2 - 1 2
D R 2- 3	Test diagnostic hypotheses	- Working hypotheses - Important and conspicuous data and information (see above)	S Provide an interactive function to assign entries/characteristics to a hypothesis 2 Provide a display to show entries/characteristics that have been assigned to a hypothesis - 1

DECISION REQUIREMENT (DR)		INFORMATION NEEDS		DESIGN SEEDS (S)	
D R 2- 4	Formulate a physiotherapeutic diagnosis	- Confirmed diagnostic hypotheses (see above)	3 S 2 - 1 4 S 2 - 1 5	Provide an interactive function to flag applicable or non-applicable hypotheses	
			S 2 - 1 6	Provide a display to show applicable and inapplicable hypotheses	
D R 3	Prepare overall finding and, if necessary, report of findings (Deciding which information is relevant to treatment and should be added to the overall report and how it should be presented)				
D R 3- 1	Select information relevant to therapy	- Physiotherapeutic diagnosis - Patient information - Data and information of the respective individual findings (see above)	S 3 - 1 S 3 - 2 S 3 - 3 S 3 - 4	Providing tools to efficiently create an overall report Providing tools to efficiently create a report of findings Providing an interactive function to efficiently add or remove information from the individual findings Providing a configurable search and filter function	
D R 3- 2	Select forms of presentation	- See above	S 3 - 5	Provide tools and displays to select appropriate display formats for different characteristics	
D	Compare results of reassessments and evaluate treatment effectiveness. (Deciding whether the treatment has a positive effect on the patient's problem or whether it needs to be				

DECISION REQUIREMENT (DR)		INFORMATION NEEDS	DESIGN SEEDS (S)
R 4 D R 4- 1	adapted) Check therapy-relevant information before reassessment	- Therapy-relevant data and information from the baseline findings and, if applicable, the previous findings	S 4 - 1 S 4 - 2 S 4 - 3 S 4 - 4 S 4 - 5 S 4 - 6 S 4 - 7
			- Presenting essential information in an aggregated and organized single view - Organize information in lists, tables, charts, and figures - Provide an interactive "drill-down" function to view details of an entry - Provide adequate displays to enable efficient inspection of features - Provide configurable displays to select an appropriate presentation form for the features - Providing a configurable search and filter function - Mapping of therapy events on a timeline
D R 4- 2	Identify trends and changes after the reassessments or before and after treatment	- Therapy-relevant data and information from the baseline findings, any previous findings, and the current reassessment - Treatments and treatment results - Possible comparative and reference values	S 4 - 8 S 4 - 9 S 4 - 1
			- Presenting key treatment outcomes (e.g., improvement/worsening of pain or function) - Use of time-based displays to show trends and highlight abnormalities - Use of comparative displays to enable comparison of characteristics - Use visual cues to draw attention to important and salient data and information - Integrating and presenting standard and comparative values - Providing tools to investigate relationships between different characteristics - Providing an interactive function to mark/highlight relevant entries and characteristics

DECISION REQUIREMENT (DR)		INFORMATION NEEDS	DESIGN SEEDS (S)
D R S D R S - 1	Evaluate therapy results and success <i>(Deciding whether the therapy was successful and which factors were essential for this)</i>	Identify trends and changes following the final findings (last reassessment) - Therapy-relevant data and information from the baseline findings and, previous findings - Treatment entries and results - Post-interventional results of relevant patient questionnaires, if applicable - Post-interventional results of the CMA, if applicable - Comparison and reference values	0 S 4 - 1 1 S 4 - 1 2 S 4 - 1 3 S 4 - 1 4
			5 S 5 - 1 S 5 - 2 S 5 - 3 S 5 - 4 S 5

DECISION REQUIREMENT (DR)		INFORMATION NEEDS	DESIGN SEEDS (S)	
D R 5- 2	Check the therapy and patient goals	- Therapy and patient goals	-	Provide an interactive function to check the achievement or non-achievement of a goal
			5	
			S	
			5	
			-	
			6	
			S	
			5	
			-	
			7	
			S	
			5	
			-	
			8	
			S	
			5	
			-	
			9	
			S	
			5	
			-	
			1	
			0	

References

1. Zaza C, Farewell VT. Musicians' playing-related musculoskeletal disorders: an examination of risk factors. *Am J Ind Med*. 1997;32(3):292-300.
2. Kok LM, Huisstede BMA, Voorn VMA, Schoones JW, Nelissen RGHH. The occurrence of musculoskeletal complaints among professional musicians: a systematic review. *Int Arch Occup Environ Health*. 2016;89(3):373-396. doi:10.1007/s00420-015-1090-6
3. Kok LM, Groenewegen KA, Huisstede BMA, Nelissen RGHH, Rietveld ABM, Haitjema S. The high prevalence of playing-related musculoskeletal disorders (PRMDs) and its associated factors in amateur musicians playing in student orchestras: A cross-sectional study. *PLOS ONE*. 2018;13(2):e0191772. doi:10.1371/journal.pone.0191772
4. Martin Fishbein, Susan E. Middlestadt, Victor Ottati, Susan Straus, Alan Ellis. Medical problems among ICSOM musicians:overview of a national survey. *Med Probl Perform Art*. 1988;3(1):1.
5. Abréu-Ramos AM, Micheo WF. Lifetime Prevalence of Upper-body Musculoskeletal Problems in a Professional-level Symphony Orchestra: Age, Gender, and Instrument-specific Results. *Med Probl Perform Art*. 2007;22(3):97.
6. Möller D, Ballenberger N, Zalpour C. The German version of the musculoskeletal pain intensity and interference questionnaire for musicians (MPIIQM-G): Translation and validation in professional orchestral musicians. *Musculoskelet Sci Pract*. 2018;37:1-7. doi:10.1016/j.msksp.2018.05.005
7. Gembris H, Heye A. Growing older in a symphony orchestra: The development of the age-related self-concept and the self-estimated performance of professional musicians in a lifespan perspective. *Music Sci*. 2014;18(4):371-391. doi:10.1177/1029864914548912
8. Wolff D, Gutzwiller J. Musikerphysiotherapie – ein Fach mit Zukunft – Kein Himmel voller Geigen. *physiopraxis*. 2010;8(6):32-35. doi:10.1055/s-0030-1262231
9. Zalpour C. Musikergesundheit als Aufgabe einer spezialisierten Musikerphysiotherapie. In: ; 2013:17-28.
10. Zalpour C, Ballenberger N, Avermann F. A physiotherapeutic approach to musicians' health – data from 614 patients from a physiotherapy clinic for musicians (INAP/O). *Front Psychol*. 2021;12. doi:10.3389/fpsyg.2021.568684
11. Niemier K, Seidel W, eds. *Funktionelle Schmerztherapie des Bewegungssystems*. 2nd ed. Springer-Verlag; 2012. doi:10.1007/978-3-642-20576-7
12. Levett-Jones T, Hoffman K, Dempsey J, et al. The 'five rights' of clinical reasoning: An educational model to enhance nursing students' ability to identify and manage clinically 'at risk' patients. *Nurse Educ Today*. 2010;30(6):515-520. doi:10.1016/j.nedt.2009.10.020
13. Müller-Staub M. Klinische Entscheidungsfindung und kritisches Denken im pflegediagnostischen Prozess. *Pflege*. 2006;19(5):275-279. doi:10.1024/1012-5302.19.5.275

14. Bartrow K. *Untersuchen und Befunden in der Physiotherapie: Untersuchungstechniken und Diagnoseinstrumente*. 3rd ed. Springer-Verlag; 2019. doi:10.1007/978-3-662-58298-5
15. Greiff C. Befund. In: Richter K, Greiff C, Weidemann-Wendt N, eds. *Der ältere Mensch in der Physiotherapie*. Springer; 2017:79-102. doi:10.1007/978-3-662-50466-6_2
16. Philp F, Faux-Nightingale A, Woolley S, de Quincey E, Pandyan A. Implications for the design of a Diagnostic Decision Support System (DDSS) to reduce time and cost to diagnosis in paediatric shoulder instability. *BMC Med Inform Decis Mak*. 2021;21(1):78. doi:10.1186/s12911-021-01446-5
17. Möller D, Backes K. Von der Biomechanik zur klinischen Anwendung. *manuelletherapie*. 2017;21(2):88-95. doi:10.1055/s-0043-105164
18. Braun T, Rieckmann A, Weber F, Grüneberg C. Current use of measurement instruments by physiotherapists working in Germany: a cross-sectional online survey. *BMC Health Serv Res*. 2018;18(1):810. doi:10.1186/s12913-018-3563-2
19. Möller D, Griefahn A. Sensorgesteuerte Bewegungsanalyse bei Musikerinnen und Musikern. *MSK – Muskuloskelettale Physiother*. 2022;26:21-26. doi:10.1055/a-1685-6633
20. Robertson G, Caldwell G, Hamill J, Kamen G, Whittlesey S. *Research Methods in Biomechanics*. Human Kinetics; 2013.
21. Richards J. *The Comprehensive Textbook of Clinical Biomechanics*. 2nd ed. Elsevier; 2018.
22. Kelleher LK, Campbell KR, Dickey JP. Biomechanical research on bowed string musicians: a scoping study. *Med Probl Perform Art*. 2013;28(4):212-218.
23. Wolf E, Möller D, Ballenberger N, Morisse K, Zalpour C. Marker-Based Method for Analyzing the Three-Dimensional Upper Body Kinematics of Violinists and Violists: Development and Clinical Feasibility. *Med Probl Perform Art*. 2019;34(4):179-190. doi:10.21091/mppa.2019.4029
24. Wolf E, Möller D, Ballenberger N, Morisse K, Zalpour C. Marker-based method for analyzing the three-dimensional upper body kinematics of violinists: Reproducibility. *Med Probl Perform Art*. 2022;37(3):176-191. doi:10.21091/mppa.2022.3025
25. Amelung P, Seidel W. Die instrumentierte Ganganalyse im Rahmen eines manualmedizinisch orientierten Diagnostik- und Therapiesettings im Krankenhaus bei Patienten mit Schmerzerkrankungen des Bewegungssystems. *Man Med*. 2005;43(6):404-413. doi:10.1007/s00337-005-0396-y
26. Passier LN, Nasciemento MP, Gesch JM, Haines TP. Physiotherapist observation of head and neck alignment. *Physiother Theory Pract*. 2010;26(6):416-423. doi:10.3109/09593980903317557
27. Peter Konrad. EMG-Fibel. Eine praxisorientierte Einführung in die kinesiologyische Elektromyographie. Version 1.1. Published online January 2011.

28. RefLabPerform | Hochschule Osnabrück. Accessed July 24, 2024. <https://www.hs-osnabrueck.de/en/reflabperform/>
29. Thomas Jöllenbeck. Bewegungsanalyse -wesentliches Element moderner sportmedizinischer Diagnostik. *Dtsch Z Für Sportmed.* 2012;(63):59-60.
30. Simon SR. Quantification of human motion: gait analysis—benefits and limitations to its application to clinical problems. *J Biomech.* 2004;37(12):1869-1880. doi:10.1016/j.jbiomech.2004.02.047
31. Loudon D, Carse B, Macdonald AS. Investigating the Use of Visualisations of Biomechanics in Physical Rehabilitation. In: Cruz-Cunha MM, Varajão J, Powell P, Martinho R, eds. *ENTERprise Information Systems. Communications in Computer and Information Science.* Springer; 2011:30-39. doi:10.1007/978-3-642-24352-3_4
32. Steinwendner J. Klinische Entscheidungsunterstützungssysteme: von der Datenrepräsentation zur künstlichen Intelligenz. In: Pfannstiel MA, Kassel K, Rasche C, eds. *Innovationen und Innovationsmanagement im Gesundheitswesen: Technologien, Produkte und Dienstleistungen voranbringen.* Springer Fachmedien; 2020:683-699. doi:10.1007/978-3-658-28643-9_36
33. Davis F, Bagozzi R, Warshaw P. User Acceptance of Computer Technology: A Comparison of Two Theoretical Models. *Manag Sci.* 1989;35:982-1003. doi:10.1287/mnsc.35.8.982
34. Karsh BT, Holden RJ, Alper SJ, Or CKL. A human factors engineering paradigm for patient safety: designing to support the performance of the healthcare professional. *BMJ Qual Saf.* 2006;15(suppl 1):i59-i65. doi:10.1136/qshc.2005.015974
35. Carayon P, Wood KE. Patient safety - The role of human factors and systems engineering. In: *Engineering the System of Healthcare Delivery.* IOS Press; 2010:23-46. doi:10.3233/978-1-60750-533-4-23
36. Miller A, Koola JD, Matheny ME, et al. Application of contextual design methods to inform targeted clinical decision support interventions in sub-specialty care environments. *Int J Med Inf.* 2018;117:55-65. doi:10.1016/j.ijmedinf.2018.05.005
37. Bates DW, Kuperman GJ, Wang S, et al. Ten commandments for effective clinical decision support: making the practice of evidence-based medicine a reality. *J Am Med Inform Assoc JAMIA.* 2003;10(6):523-530. doi:10.1197/jamia.M1370
38. Rice H, Garabedian PM, Shear K, et al. Clinical Decision Support for Fall Prevention: Defining End-User Needs. *Appl Clin Inform.* 2022;13(3):647-655. doi:10.1055/s-0042-1750360
39. Kuperman GJ, Bobb A, Payne TH, et al. Medication-related Clinical Decision Support in Computerized Provider Order Entry Systems: A Review. *J Am Med Inform Assoc JAMIA.* 2007;14(1):29-40. doi:10.1197/jamia.M2170
40. Horsky J, Schiff GD, Johnston D, Mercincavage L, Bell D, Middleton B. Interface design principles for usable decision support: A targeted review of best practices for clinical prescribing interventions. *J Biomed Inform.* 2012;45(6):1202-1216. doi:10.1016/j.jbi.2012.09.002

41. Sedlmair M, Meyer M, Munzner T. Design Study Methodology: Reflections from the trenches and the stacks. *IEEE Trans Vis Comput Graph*. 2012;18(12):2431-2440. doi:10.1109/TVCG.2012.213
42. Gulliksen J, Göransson B, Boivie I, Blomkvist S, Persson J, Cajander Å. Key principles for user-centred systems design. *Behav Inf Technol*. 2003;22(6):397-409. doi:10.1080/01449290310001624329
43. Crandall B, Klein G, Klein GA, Hoffman RR, Hoffman RR, Hoffman SRSRR. *Working Minds: A Practitioner's Guide to Cognitive Task Analysis*. MIT Press; 2006.
44. Militello LG, Klein G. Decision-Centered Design. In: Lee JD, Kirlik A, eds. *The Oxford Handbook of Cognitive Engineering*. Oxford University Press; 2013:261-271. doi:10.1093/oxfordhb/9780199757183.013.0016
45. Clark R, Feldon D, Van Merriënboer JJG, Yates K, Early S. Cognitive task analysis. *Handb Res Educ Commun Technol*. Published online January 1, 2008:577-593.
46. Schemmann H, Rensing N, Zalpour C. Musculoskeletal Assessments Used in Quantitatively Based Studies About Posture and Movement in High String Players: A Systematic Review. *Med Probl Perform Art*. 2018;33(1):56-71. doi:10.21091/mppa.2018.1009
47. Spahn C. Musiker – Behandlung und Prävention in der Musikermedizin. In: Badura B, Ducki A, Schröder H, Klose J, Meyer M, eds. *Fehlzeiten-Report 2015: Neue Wege für mehr Gesundheit - Qualitätsstandards für ein zielgruppenspezifisches Gesundheitsmanagement*. Fehlzeiten-Report. Springer; 2015:227-231. doi:10.1007/978-3-662-47264-4_20
48. Spahn C, Richter B, Altenmüller E. *MusikerMedizin: Diagnostik, Therapie und Prävention von musikerspezifischen Erkrankungen*. 1st ed. Schattauer; 2010.
49. Shan G, Visentin P, Nusseck M, Spahn C. Investigating Aspects of Movement in Violin Performance. In: *Handbook of Human Motion*. Springer International Publishing; 2018:1803-1820. doi:10.1007/978-3-319-14418-4_108
50. Lohse-Busch H. Funktionelle Diagnostik des Bewegungssystems. In: Ebinger F, ed. *Schmerzen bei Kindern und Jugendlichen: Ursachen, Diagnostik und Therapie*. 2011th ed. Thieme Verlag; 2011. doi:10.1055/b-0034-38295
51. Higgs J, Jones M, Loftus S, Christensen N. *Clinical Reasoning in the Health Professions*.; 2008.
52. Jones MA, Gail Jensen, Ian Edwards. Clinical Reasoning in physiotherapy. In: Higgs J, Jones MA, Loftus S, Christensen N, eds. *Clinical Reasoning in the Health Professions*. Elsevier Health Sciences; 2008:245-254.
53. Trocha M, Aigner AK, Brandt H, et al. Befundest du noch – oder diagnostizierst du schon? *physioscience*. 2014;10(01):24-28. doi:10.1055/s-0034-1365977
54. Konrad P. The abc of emg. *Pract Introd Kinesiol Electromyogr*. 2005;1.
55. Best R, Begg R. Overview of Movement Analysis and Gait Features. *Comput Intell Mov*

- Sci Neural Netw Emerg Tech*. Published online January 1, 2006. doi:10.4018/978-1-59140-836-9.ch001
56. Coutts F. Gait analysis in the therapeutic environment. *Man Ther.* 1999;4(1):2-10. doi:10.1016/S1356-689X(99)80003-4
 57. Patrick Klaus Klein Flörsheim-Dalsheim. *Risiko-Screening in den Ausbildungsstrukturen der Physiotherapie – Curriculare Umsetzung in den Ausbildungseinrichtungen und dessen Einfluss auf die Fähigkeit der Auszubildenden und Studierenden*. Universität Ulm; 2018.
 58. Holtzblatt K, Wendell JB, Wood S. *Rapid Contextual Design: A How-to Guide to Key Techniques for User-Centered Design*. Elsevier; 2005.
 59. Daniels N, Gillen P, Casson K, Wilson I. STEER: Factors to Consider When Designing Online Focus Groups Using Audiovisual Technology in Health Research. *Int J Qual Methods*. 2019;18:1609406919885786. doi:10.1177/1609406919885786
 60. Griefahn A, Wolf E, Zalpour C. Wie kann die Dokumentation in der Physiotherapie durch die Digitalisierung effektiver und effizienter werden? - Eine Delphi-Studie. *physioscience*. Published online April 28, 2020. doi:10.1055/a-1113-6688
 61. Kontaxis A, Cutti AG, Johnson GR, Veeger HEJ. A framework for the definition of standardized protocols for measuring upper-extremity kinematics. *Clin Biomech*. 2009;24(3):246-253. doi:10.1016/j.clinbiomech.2008.12.009
 62. Sharp H, Preece J, Rogers Y. *Interaction Design: Beyond Human-Computer Interaction*. 5th ed. Wiley; 2019.
 63. Jünger S, Payne SA, Brine J, Radbruch L, Brearley SG. Guidance on Conducting and REporting DELphi Studies (CREDES) in palliative care: Recommendations based on a methodological systematic review. *Palliat Med*. 2017;31(8):684-706. doi:10.1177/0269216317690685
 64. Tack C. Artificial intelligence and machine learning | applications in musculoskeletal physiotherapy. *Musculoskelet Sci Pract*. 2019;39:164-169. doi:10.1016/j.msksp.2018.11.012
 65. Remedios SM, Armstrong DP, Graham RB, Fischer SL. Exploring the Application of Pattern Recognition and Machine Learning for Identifying Movement Phenotypes During Deep Squat and Hurdle Step Movements. *Front Bioeng Biotechnol*. 2020;8. doi:10.3389/fbioe.2020.00364
 66. Cao Z, Hidalgo G, Simon T, Wei SE, Sheikh Y. OpenPose: Realtime Multi-Person 2D Pose Estimation Using Part Affinity Fields. *IEEE Trans Pattern Anal Mach Intell*. 2021;43(1):172-186. doi:10.1109/TPAMI.2019.2929257
 67. Weber F, Rieckmann A, Grueneberg C. Feasibility report of the usage of the mobile-app TheraAssist to improve documentation and usage of assessments in physiotherapy practice. *Physiotherapy*. 2016;102:e274. doi:10.1016/j.physio.2016.10.347
 68. Gait Analysis. Qualisys. Accessed April 4, 2025. <https://www.qualisys.com/analysis/gait/>

69. Granviken F, Meisingset I, Vasseljen O, Bach K, Bones AF, Klevanger NE. Acceptance and use of a clinical decision support system in musculoskeletal pain disorders - the SupportPrim project. *BMC Med Inform Decis Mak*. 2023;23(1):293. doi:10.1186/s12911-023-02399-7
70. Mikołajewska E, Masiak J, Mikołajewski D. Applications of Artificial Intelligence-Based Patient Digital Twins in Decision Support in Rehabilitation and Physical Therapy. *Electronics*. 2024;13(24):4994. doi:10.3390/electronics13244994
71. Hao J, Yao Z, Tang Y, Remis A, Wu K, Yu X. Artificial Intelligence in Physical Therapy: Evaluating ChatGPT's Role in Clinical Decision Support for Musculoskeletal Care. *Ann Biomed Eng*. 2025;53(1):9-13. doi:10.1007/s10439-025-03676-4
72. Ploderer B, Fong J, Klaic M, et al. How Therapists Use Visualizations of Upper Limb Movement Information From Stroke Patients: A Qualitative Study With Simulated Information. *JMIR Rehabil Assist Technol*. 2016;3(2). doi:10.2196/rehab.6182
73. Liakopoulou C, Mansourvar M, Bø, et al. Data Vizualization Dashboards in Robotic Rehabilitation. In: *Public Health and Informatics*. IOS Press; 2021:278-282. doi:10.3233/SHTI210164
74. Wagner M, Slijepcevic D, Horsak B, Rind A, Zeppelzauer M, Aigner W. KAVAGait: Knowledge-Assisted Visual Analytics for Clinical Gait Analysis. *IEEE Trans Vis Comput Graph*. 2019;25(3):1528-1542. doi:10.1109/TVCG.2017.2785271
75. Chan GYY, Nonato LG, Chu A, Raghavan P, Aluru V, Silva CT. Motion Browser: Visualizing and Understanding Complex Upper Limb Movement Under Obstetrical Brachial Plexus Injuries. *IEEE Trans Vis Comput Graph*. 2020;26(1):981-990. doi:10.1109/TVCG.2019.2934280
76. Evans RS. Electronic Health Records: Then, Now, and in the Future. *Yearb Med Inform*. 2016;(Suppl 1):S48-S61. doi:10.15265/IYS-2016-s006
77. Ayaz M, Pasha MF, Alzahrani MY, Budiarto R, Stiawan D. The Fast Health Interoperability Resources (FHIR) Standard: Systematic Literature Review of Implementations, Applications, Challenges and Opportunities. *JMIR Med Inform*. 2021;9(7):e21929. doi:10.2196/21929
78. Bathelt F, Lorenz S, Weidner J, Sedlmayr M, Reinecke I. Application of Modular Architectures in the Medical Domain - a Scoping Review. *J Med Syst*. 2025;49(1):27. doi:10.1007/s10916-025-02158-3
79. Weik L, Fehring L, Mortsiefer A, Meister S. Understanding inherent influencing factors to digital health adoption in general practices through a mixed-methods analysis. *Npj Digit Med*. 2024;7(1):1-16. doi:10.1038/s41746-024-01049-0
80. Fauntroy V, Fyock M, Hansen-Honeycutt J, Nolton E, Ambegaonkar JP. Using the Selective Functional Movement Assessment for the Evaluation of Dancers' Functional Limitations and Dysfunctions: A Critically Appraised Topic. *J Sport Rehabil*. 2019;28(8):891-896. doi:10.1123/jsr.2018-0054
81. Bullock GS, Hughes T, Sergeant JC, Callaghan MJ, Riley RD, Collins GS. Clinical Prediction Models in Sports Medicine: A Guide for Clinicians and Researchers. *J*

Orthop Sports Phys Ther. 2021;51(10):517-525. doi:10.2519/jospt.2021.10697

82. Gross DP, Armijo-Olivo S, Shaw WS, et al. Clinical Decision Support Tools for Selecting Interventions for Patients with Disabling Musculoskeletal Disorders: A Scoping Review. *J Occup Rehabil.* 2016;26:286-318. doi:10.1007/s10926-015-9614-1
83. Soares CO, Pereira BF, Pereira Gomes MV, Marcondes LP, de Campos Gomes F, de Melo-Neto JS. Preventive factors against work-related musculoskeletal disorders: narrative review. *Rev Bras Med Trab.* 2020;17(3):415-430. doi:10.5327/Z1679443520190360

Supplementary Files

Multimedia Appendixes

User requirements (UR) formulated as user stories based on user needs for decision support.

URL: <http://asset.jmir.pub/assets/642b2811143e336d59d2e9bc79e91dfe.docx>

Cognitive tasks and the associated strategies, (potential) errors or difficulties, and critical hints of the domain experts.

URL: <http://asset.jmir.pub/assets/8323feff3cfd63899f2a36f32c3fbbb8.docx>

Key decision requirements (DR), associated information needs and design seeds (S) to support decision-making.

URL: <http://asset.jmir.pub/assets/cda88aa09ae7561116a541ae9cee1586.docx>