

Designing for clinical understanding: Therapist-focused visualization design for upper-limb rehabilitation

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Abstract: Many visualization systems have been developed to present kinematic data in upper-limb rehabilitation, but few are structured around clinical interpretive workflows. This study introduces a therapist-focused visualization design intended to align upper-limb kinematic data with clinical reasoning processes. The design was developed through a focused mini-review of existing systems and demonstrated using a prototype dashboard. It integrates spatial, temporal, and quantitative information into a single display. By structuring commonly used kinematic metrics and qualitative movement views into a clear format, the proposed design provides a conceptual foundation for developing more clinically informed visualization systems in rehabilitation.

Keywords: Visualization design, upper-limb rehabilitation, kinematic data, human-centered design

1 Introduction

Designing effective user experiences in healthcare is essential as digital health systems become increasingly integrated into rehabilitation practice. Within the scope of healthcare design, particularly in user experience in medical service design and digital health systems, data visualization is crucial for transforming complex kinematic data into information that therapists and patients can easily understand (Karlsson et al., 2024; Maradani & Levkowitz, 2017). Recent improvements in motion capture and sensor-based technologies have made it possible to accurately track joint positions and orientations in three-dimensional space, providing detailed kinematic information for upper-limb rehabilitation (Latif et al., 2023). Technologies such as inertial measurement units (IMUs), robotic rehabilitation devices, and vision-based monitoring systems now allow continuous recording of upper-limb movements during therapy sessions, generating large volumes of time-series kinematic data. These data are then processed to provide kinematic metric information, including joint range of motion (ROM), velocity, acceleration, smoothness, and trajectory-related measures that together provide objective indicators of motor recovery.

However, despite these technological advancements, therapists frequently have difficulties in analyzing such data to facilitate therapeutic decision-making, track progress, or communicate findings to patients effectively (Hill et al., 2022; Pystina et al., 2022). The volume and multidimensional nature of kinematic data can overwhelm clinicians, particularly when raw numerical outputs are not translated into clinically meaningful representations (Alt Murphy & Häger, 2015). Moreover, there is currently no standardized approach for transforming raw kinematic measurements into structured visual formats that align with therapists' interpretive reasoning and workflow practices (Schwarz et al., 2019). As a result, the analytical potential of motion capture systems often remains underutilized in routine rehabilitation settings.

Data visualization offers a means to bridge the gap between computational measurement and human understanding by transforming raw motion data into intuitive visual forms. Well-designed visual representations can support therapists in observing movement patterns, evaluating recovery trends, and delivering meaningful feedback (Ramesh et al., 2024). In this context, visualization is not only an analysis tool but also a way to communicate data-driven insights in a form that supports clinical reasoning (Loudon & Macdonald, 2011).

Although interest in visualization for rehabilitation has increased, many existing systems remain disconnected and fragmented (Ballinger et al., 2016; Caldeira et al., 2021). Many studies introduce visualization concepts or prototypes, yet few include therapist validation or explicitly address how visualization supports interpretive practices (Ploderer et al., 2016). Moreover, many designs focus on single kinematic variables, such as movement trajectory or range of motion, instead of providing multi-metric and interactive views that better reflect the complexity of upper-limb movement. The lack of comprehensive, user-centered visualization designs restricts the interpretability and therapeutic applicability of current systems (Gill et al., 2025; Van Ommeren et al., 2018).

Therefore, this study examines how upper-limb kinematic data are currently visualized in rehabilitation systems and identifies design gaps that limit clinical interpretability. Based on a focused mini-review, we propose a therapist-centered visualization structure that integrates spatial, temporal, and quantitative representations into a coordinated multi-view design aligned with clinical reasoning processes.

To achieve this aim, the paper is structured as follows. Section 2 explains the criteria and methods used to complete the focused mini-review. Section 3 presents the findings of the review, analyzing commonly used kinematic metrics and existing visualization approaches, and identifying limitations and fragmentation in current systems. Based on these findings, Section 4 introduces the proposed visualization design. Section 5 demonstrates the design through a prototype implementation. Section 6 discusses broader implications for healthcare design and rehabilitation practice. Section 7 outlines the study's limitations and provides directions for future work. Finally, Section 8 concludes the paper.

2 Methods

A focused mini-review was conducted to identify representative visualization systems for upper-limb kinematic data in rehabilitation. Compared to a systematic review, which prioritizes methodological completeness and quantitative synthesis of clinical outcomes, or a scoping review, which typically maps the full breadth of a research field, a focused mini-review is a short, design-oriented synthesis aimed at extracting recurring patterns and design strategies from a representative subset of the literature. This format was chosen because the study's purpose is conceptual: to identify how kinematic data are currently visualized and where therapist-centered design gaps exist, rather than to produce an exhaustive evidence base. The trade-off is that the resulting set is smaller and not intended for statistical generalization. We will discuss this further in Section 7.

2.1 Search and selection process

We used the AI-assisted academic discovery tool Elicit (indexing Semantic Scholar and OpenAlex, ~138 million papers) for three specific tasks: (i) semantic retrieval of the 500 most relevant papers given a structured query on motion data, user needs, and visualization in upper-limb rehabilitation; (ii) abstract-level screening against seven explicit inclusion criteria: upper-limb focus, motion-data collection, user-centered approach, visualization component, clinical decision-making focus, dynamic motion analysis, and clinical applicability; and (iii) structured data extraction from each retained abstract across eight predefined columns (motion data capture, user needs, visualization strategy, framework design, interpretation support, decision support, effectiveness, and implementation). The AI did not make final inclusion decisions, all outputs were treated as candidate material for human review. This human-supervised use of AI-assisted retrieval is consistent with recent guidance on combining AI tools with manual oversight to balance discovery breadth with conceptual precision (Lau & Golder, 2025).

2.2 Manual refinement and final selection

After AI screening reduced the pool to 41 candidates, we conducted a manual full-text review and applied an additional refinement criterion: studies were retained only if they reported at least one kinematic metric aligned with the classification proposed by De Los Reyes-Guzmán et al. (2014). This step ensured conceptual coherence with the metric foundation of the proposed visualization design and resulted in a final set of 8 studies (J. Bai et al., 2019; L. Bai, 2021; Bertomeu-Motos et al., 2023; Culmer et al., 2011; Klaassen et al., 2017; Lee et al., 2020; Ploderer et al., 2016; Wisedsri et al., 2024). Figure 1 summarizes the full selection flow.

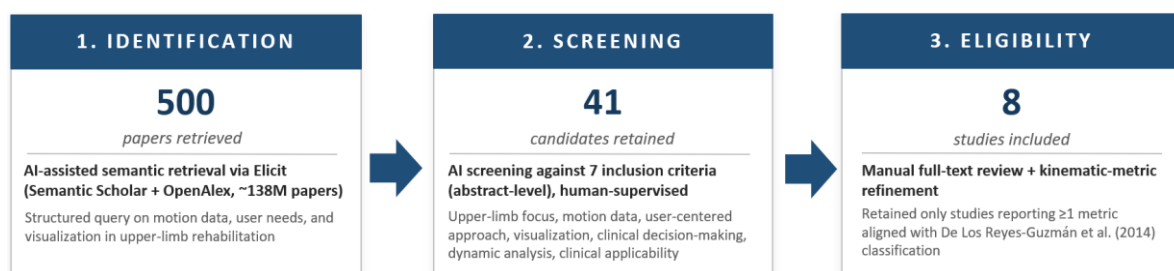


Figure 1. Selection flow of the focused mini-review. Elicit was used for semantic retrieval and abstract-level screening against seven inclusion criteria; manual full-text review with a kinematic-metric refinement criterion (De Los Reyes-Guzmán et al., 2014) resulted in the final eight studies.

A literature-based starting point was chosen because the study's objective at this stage is to synthesize and structure existing visualization patterns and identify under-addressed therapist-centered needs. All eight reviewed studies already involve clinicians, therapists, or patients in co-design or validation activities (43 therapists in total), providing embedded stakeholder input. Complementary empirical methods, including semi-structured therapist interviews and observational studies in clinical settings, are planned as the next stage to validate and refine the proposed design (see Section 7).

2.3 Synthesis and analysis approach

The selected studies were examined through structured qualitative synthesis across four dimensions: (1) Kinematic metrics employed, following the classification established in prior research (De Los Reyes-Guzmán et al., 2014); (2) qualitative

kinematic visual representations, such as trajectory playback or joint position heatmaps; (3) visualization techniques used, including line graphs, bar charts, area plots, etc.; and (4) validation approach and participant group. The synthesis did not aim to statistically compare systems but to extract recurring design strategies, limitations in multi-metric integration, and gaps in therapist-centered interpretability. These findings served as the explicit design rationale for the proposed visualization prototype.

3 Results

This section presents the findings derived from the focused mini-review. The analysis examines recurring patterns in kinematic metric selection, visualization techniques, and therapist interpretive practices across the reviewed studies. Based on these patterns, key visualization requirements are subsequently derived to inform the proposed design.

3.1 Patterns in kinematic metrics and visualization practices

We summarize the relationships among kinematic metrics, qualitative kinematic visuals, and visualization techniques from eight reviewed studies (Figure 2). ROM and velocity were the most frequently used kinematic measures and were typically depicted in line graphs to show changes in movement amplitude and timing. Movement time, jerk, and number of velocity peaks were used less consistently across studies. In one case, smoothness was described conceptually as “higher smoothness reflects better motor control and coordination” without specifying its computational method, reflecting broader inconsistency across studies (Wisedsri et al., 2024). Similarly, the metric referred to as “movement unit number” in L. Bai (2021) is classified here as “number of velocity peaks”, following the terminology used by De Los Reyes-Guzmán et al. (2014).

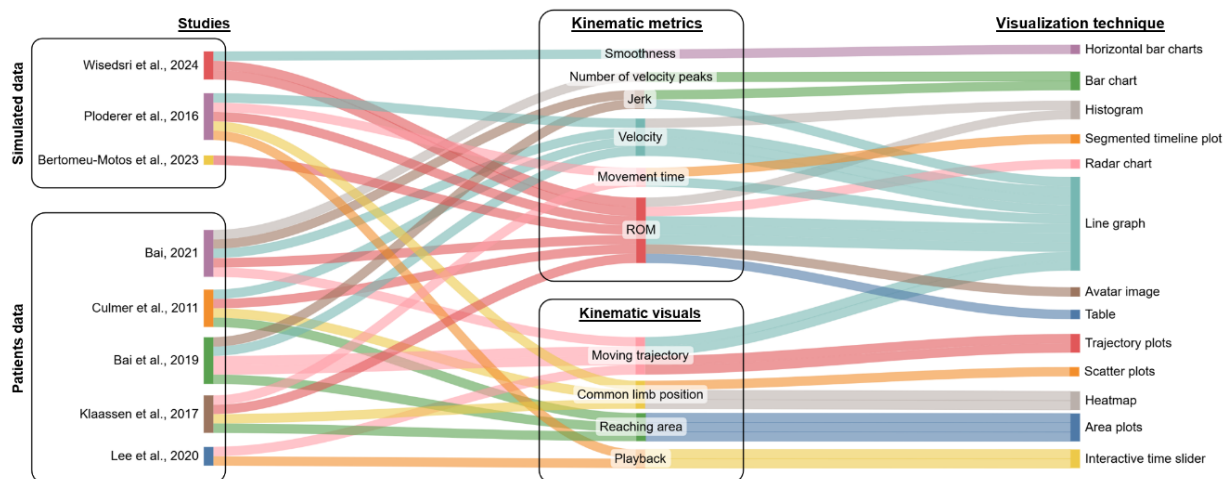


Figure 2. Summary of the results from the reviewed articles.

In addition to quantitative metrics, several studies also incorporated qualitative spatial-temporal representations, including trajectory plots, heatmaps of limb positions, workspace area plots, and playback views. These visuals complement numerical metrics by providing spatial-temporal context for identifying irregularities or reduced reach during therapy. Among these, five studies (J. Bai et al., 2019; Bertomeu-Motos et al., 2023; Culmer et al., 2011; Klaassen et al., 2017; Lee et al., 2020) implemented comparative visualization designs that enabled side-by-side observation of affected and unaffected limbs or comparisons between patient and healthy reference movements. Such comparative layouts were particularly useful for detecting asymmetrical movement patterns and quantifying rehabilitation progress across sessions.

In terms of visualization techniques, line graphs were the most frequently used to represent kinematic metrics, followed by area plots for reaching-area analysis and interactive time sliders for playback. A few studies also applied more specialized techniques such as segmented timeline plots, radar charts, or avatar-based displays to summarize multi-joint behavior.

Studies using simulated data (Bertomeu-Motos et al., 2023; Ploderer et al., 2016; Wisedsri et al., 2024) tended to emphasize quantitative metrics and interface validation, while those using patient data (J. Bai et al., 2019; L. Bai, 2021; Culmer et al., 2011; Klaassen et al., 2017; Lee et al., 2020) placed greater weight on visual interpretability and clinical usability, often combining quantitative metrics with spatial-temporal representations such as trajectory and reaching-area views. This pattern suggests that simulated-data studies were oriented toward validating visualization prototypes under controlled conditions, whereas patient-data studies gave more attention to therapist interpretation and progress tracking.

through the combined use of metric-based and spatial views. Across all reviewed papers, 43 therapists participated in co-design or validation activities, reflecting active professional involvement in shaping visualization requirements.

In addition to summarizing commonly used metrics and visualizations, the review identified recurring interpretation tasks carried out by therapists. These included assessing movement quality, detecting compensatory patterns, monitoring changes over time, and communicating rehabilitation progress to patients. However, most existing systems show only one type of measurement or one view at a time, rather than bringing different types of information together in a single visualization.

3.2 Derived visualization requirements

Based on these findings, three main therapist-centered visualization needs were identified. First, therapists require visualization to perform a systematic performance assessment, including the detection of compensatory movement patterns, so they can determine whether exercises are executed correctly and within safe movement limits. Prior research often used metrics such as ROM, speed, and smoothness-related variables to assess the timing, amplitude, and coordination of movement. Therefore, effective visualization should focus on clinically relevant kinematic metrics and present them in a structured format that allows therapists to quickly assess movement performance.

Second, the review highlighted the importance of progress tracking across repetitions and sessions. Several studies used comparative layouts to observe asymmetry between affected and unaffected limbs or to track changes over time. To support this reasoning process, visualization should include elements for synchronized temporal alignment and comparison analysis that allow for systematic evaluation at the repetition level.

Third, therapists often use visualization tools to communicate rehabilitation outcomes to patients and interdisciplinary teams. It was reported that a clear graphical representation of ROM, smoothness, and symmetry was helpful for giving feedback and motivating patients. Visualization design should therefore emphasize clarity, visual comparability, and structured presentation to support interpretability and communication.

In addition to these three primary objectives (assessing performance, tracking progress, and communicating outcomes), the review also suggests that good visualization should include both quantitative metrics and qualitative spatial-temporal representations. Trajectory plots, workspace visualizations, and replay mechanisms were frequently employed to contextualize numerical indicators and support interpretation of movement quality.

In conclusion, these findings suggest that effective visualization for upper-limb rehabilitation should combine multiple movement metrics, comparison features, and spatial and temporal views in a coordinated way that supports therapists' interpretation tasks. However, many existing systems present these elements separately rather than using a structured, therapist-centered design approach.

This gap underscores the need for a visualization design explicitly organized around clinical reasoning processes and the integration of quantitative and spatial information. The following section presents a visualization design derived from these requirements.

4 Visualization design

Based on the therapist-centered needs identified in Section 3.2, the proposed visualization design turns these requirements into coordinated visual components supported by structured kinematic data processing. Figure 3 provides an overview of the design, showing the relationship between therapist-centered needs, kinematic data processing, and the coordinated multi-view visualization components.

4.1 Data structure and processing logic

The visualization design is based on 3D upper-limb movement data collected during rehabilitation exercises. Consistent with the findings of the focused mini-review, the system is designed to work with repeated upper-limb movement cycles recorded using motion capture technologies such as depth sensors, IMUs, or marker-based systems.

The dataset consists of frame-by-frame 3D joint position data that includes repeated movement cycles, such as shoulder flexion, abduction, and elbow flexion. To prepare such data for visualization, several **preprocessing steps** are required. These include segmentation to identify individual repetitions, temporal normalization to allow comparisons across movements, and cleaning procedures to handle missing or noisy values. After these steps, the data proceed to the **kinematic metrics extraction** step. In this stage, the system calculates the key clinical metrics most frequently used in prior studies. These include ROM, movement time, linear and angular velocity, and smoothness indicators such as dimensionless jerk and the number of velocity peaks. In addition to quantitative metrics, spatial-temporal representations are derived, including 3D joint trajectories and workspace point distributions.

These processed outputs form the analytical foundation of the visualization design, ensuring that both metric-based summaries and spatial representations are available for coordinated interpretation.

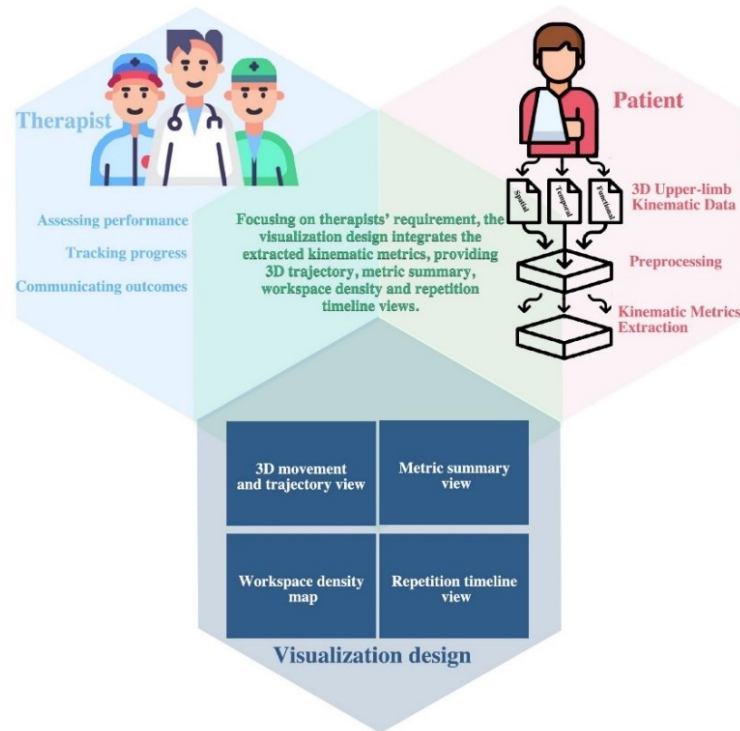


Figure 3. Conceptual overview of the therapist-focused visualization design, showing the integration of therapist requirements, kinematic data processing, and coordinated multi-view components for upper-limb rehabilitation.

4.2 Visualization components

Drawing on patterns identified in the mini-review and the characteristics of the dataset, the design integrates four interconnected visualization components, each addressing specific analytical and interpretive requirements within rehabilitation practice.

1. **3D movement and trajectory view:** Demonstrates the trajectories of limb movement paths for all repetitions over time. This perspective highlights spatial precision and enables therapists to detect compensatory movements and asymmetries while contextualizing quantitative metrics within observable motion patterns.
2. **Workspace density map:** Maps all joint positions onto a two or three-dimensional plane to generate a heatmap of reachable workspace areas. Denser areas signify regularly exploited zones, while sparse areas indicate underutilized mobility ranges. This perspective offers a precise evaluation of reach amplitude and functional workspace coverage.
3. **Metric summary view:** Displays consolidated quantitative metrics, including ROM, smoothness, and velocity, in bar or line charts. These representations elucidate disparities between affected and unaffected limbs or between repetitions, facilitating therapists' interpretation of alterations in movement quality.
4. **Repetition timeline view:** Since the dataset includes multiple repetitions within a single session, this view represents the continuous temporal flow of performance with embedded repetition markers. The timeline enables synchronized playback of motion data, showing how key kinematic metrics, such as ROM, smoothness, and velocity change throughout the session. Rather than isolating individual repetitions, this view emphasizes temporal continuity, helping therapists observe variation, stability, and fatigue patterns as the session progresses.

4.3 Interaction and visual encoding strategy

Color coding distinguishes between limbs, while interactive filters allow users to focus on specific data from different limbs. Coordinated interactions synchronize all visualization components through a shared temporal reference. When the user moves the timeline cursor, all panels update simultaneously, including the 3D trajectory view and the metric plots. This synchronized interaction allows therapists to observe how spatial movement patterns and quantitative metrics evolve at the same moment in time. These interaction mechanisms balance overview and detail, supporting both rapid assessment and deeper analytical exploration.

5 Prototype demonstration

To illustrate how the proposed visualization design operates in practice, a prototype dashboard was implemented using the publicly available IntelliRehabDS dataset (Miron et al., 2021), which contains 3D upper-limb movement recordings from 15 patients and 14 healthy participants captured with a Microsoft Kinect sensor. The prototype builds on a previously published kinematic analysis tool, CKATool (Latif & Georgiev, 2025), which already provided a synchronized playback environment for kinematic data. The contribution of the present study is not to introduce an entirely new tool, but to reorganize the prototype around the four therapist-centered visualization components derived from the mini-review (Section 4.2). Implementing this design framework required: (1) **adapting** the 3D movement and trajectory view into a paired affected vs. normal layout to support compensation detection; (2) **adding** a new workspace density map for reach-amplitude assessment, which was not present in the baseline tool; (3) **curating** the metric summary view by retaining only those clinically meaningful metrics identified in the mini-review (ROM, linear and angular velocity, movement time, number of velocity peaks, and jerk) and restructuring them around an affected vs. normal comparison; and (4) **retaining** the synchronized repetition timeline from the baseline tool, since it directly supports the temporal-continuity component of the framework. These four design moves are highlighted as callouts A–D in Figure 4.

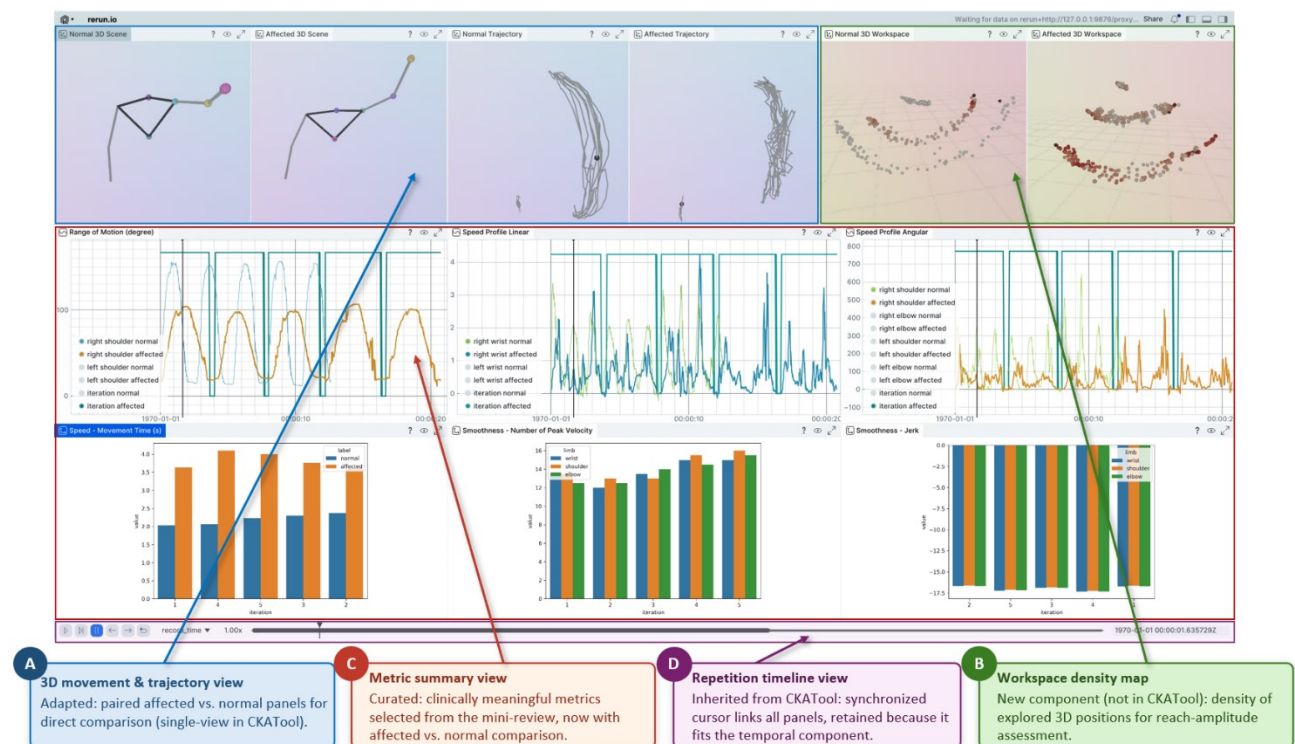


Figure 4. Prototype dashboard implementing the four therapist-centered visualization components from Section 4.2. Callouts indicate how each component was realized relative to the baseline kinematic analysis tool (CKATool): (A) 3D movement and trajectory view, adapted into a paired affected vs. normal layout; (B) workspace density map, a new component for reach-amplitude assessment; (C) metric summary view, curated to retain clinically meaningful metrics from the mini-review and restructured for affected vs. normal comparison; (D) repetition timeline view, inherited from CKATool and retained because it directly supports the temporal-continuity component of the framework.

As shown in Figure 4, panel (A) presents **3D movement and trajectory views** for both affected and normal participants, allowing direct visual comparison of movement paths and spatial accuracy. Panel (B) illustrates the **workspace density map**, which visualizes the area covered by each limb throughout movement. Denser regions represent more frequently used positions, providing insight into movement control and functional reach. Panel (C) displays a **metric summary view** as quantitative metrics, including ROM, linear and angular velocity, movement duration, and smoothness indicators such as jerk and the number of velocity peaks. Panel (D) shows the **repetition timeline**, enabling synchronized playback across all panels and linking temporal motion events with corresponding changes in kinematic metrics during each repetition.

Color and interaction cues implemented in the prototype further enhance interpretability. As shown in Figure 4, color coding is applied consistently across all panels to distinguish between limbs and kinematic metrics, while maintaining visual correspondence between the movement playback, trajectory, and workspace. This enables therapists to easily compare spatial precision, movement symmetry, and performance trends. Interactive filters are implemented in selected metrics panels. These filters allow users to isolate specific limbs or metrics for detailed examination or data comparison.

Additionally, it reduces the complexity of presenting large amounts of data from several limbs simultaneously. Therapists can activate and deactivate specific data in the visualization panels based on their analytical focus during the session. The synchronized timeline interaction ensures that moving the temporal cursor updates all visualization panels simultaneously, enabling therapists to relate quantitative metric changes directly to observable motion patterns.

Through this prototype implementation, the visualization design is demonstrated as an integrated, multi-view analytical environment that combines metric-based summaries, spatial context, and temporal alignment to support therapist-centered interpretation of upper-limb movement data.

6 Discussion and implications

6.1 Reflection on the visualization design

The proposed visualization design was developed by combining insights from the focused mini-review and translating common therapist interpretation tasks into structured visual components. Rather than introducing new computational metrics, the design focuses on organizing existing kinematic representations to better support therapist reasoning.

The design consists of three conceptual layers: therapist-oriented objectives, structured kinematic data processing, and coordinated multi-view visualization components. This layered structure shows how quantitative metrics, spatial and temporal representations, and interaction mechanisms work together to support clinical interpretation. By structuring the visualization around assessment, progress tracking, and communication tasks, the design moves beyond simple metric display toward practical clinical support.

By synchronizing trajectory views, workspace maps, metric summaries, and repetition timelines through the same timeline, the system allows therapists to see how numerical values relate to actual movement patterns. This makes it easier to understand how changes in kinematic metrics correspond to visible movement behavior.

6.2 Advancement beyond prior visualization approaches

Compared with the visualization approaches identified in the mini-review, the proposed design emphasizes a structured integration rather than isolated metric display. Previous studies often focused on visualizing isolated kinematic metrics such as ROM, velocity, or trajectory without explicitly linking them to therapist reasoning or decision-making. For instance (J. Bai et al., 2019; Bertomeu-Motos et al., 2023; Culmer et al., 2011) presented quantitative visualizations of upper limb performance using static plots and bar charts to report ROM or velocity changes, but offered little discussion of how therapists interpreted these visuals. Similarly, Klaassen et al. (2017) employed comparable visualizations of trajectory and smoothness metrics for case analyses, focusing primarily on measurement rather than interpretive support.

While prior works demonstrated the technical feasibility of motion visualization, therapist perspectives were often incorporated primarily during validation rather than as a guiding force in the design process. Across the reviewed studies, therapist involvement tended to focus on usability evaluation or post-implementation feedback rather than on structuring visualization components around clinical reasoning tasks. Although the study by Ploderer et al. (2016) adopted a user-centered design approach, the emphasis remained on usability and information presentation rather than explicitly structuring visualizations around therapist reasoning processes. Likewise, Lee et al. (2020) consulted therapists to evaluate usability and engagement, but did not explicitly link visualization design to clinical reasoning tasks. In Wisedsri et al. (2024), where visualization was used for therapist feedback, the smoothness metric was conceptually described (“higher smoothness reflects better motor control and coordination”) without specifying a computational basis or interpretive framework. These examples illustrate a broader tendency for visualization structures to be shaped by data representation logic rather than by therapist assessment workflows.

In contrast, the present visualization design derives its structure from synthesized interpretive priorities across the literature. Instead of introducing new metrics, it reorganizes established kinematic representations into a coordinated multi-view architecture aligned with assessment, compensation detection, and longitudinal monitoring. The integration of synchronized temporal interaction further strengthens the connection between spatial motion patterns and quantitative indicators, supporting moment-by-moment interpretive reasoning.

This shift from metric-centric visualization toward reasoning-oriented structure represents a conceptual advancement in the design of rehabilitation visualization systems.

6.3 Implications and challenges for practice

From a design research perspective, this study highlights the importance of grounding visualization structures in end-user reasoning processes rather than solely in data characteristics. In healthcare contexts, effective visualization must prioritize interpretive clarity, contextual integration, and cognitive coherence. The coordinated multi-view structure demonstrated

here illustrates how spatial, temporal, and quantitative representations can be aligned to support domain-specific reasoning tasks.

For rehabilitation practice, the visualization design offers a structured way to organize kinematic data, enhancing understanding and communication. By synchronizing trajectory views, metric summaries, and temporal progression within a unified analytical environment, therapists can relate numerical changes to observable movement behavior more directly. Such integration may support clearer feedback, structured progress monitoring, and improved communication with patients and interdisciplinary teams.

At the same time, several challenges remain. Translating raw kinematic data into clinically meaningful visual feedback requires a careful balance between informational richness and cognitive load. Therapists may vary their interpretive strategies, clinical priorities, and tolerance for analytical complexity. Visualization systems must therefore remain adaptable and sensitive to diverse clinical contexts.

Future development may further integrate computational analysis capabilities with therapist-centered visualization structures, creating hybrid platforms that support both research and clinical applications. Empirical evaluation within live or simulated rehabilitation workflows will be essential to assess interpretability, workflow integration, and practical impact.

7 Limitations and future work

While this study proposes a structured visualization design for upper-limb kinematic data, several limitations should be acknowledged. First, the design was developed based on a review of existing literature and demonstrated using a public dataset (IntelliRehabDS), rather than through direct collaboration with therapists. Therefore, the system has not yet been tested within real clinical workflows. Future work should involve rehabilitation professionals in participatory design and usability testing to examine whether the system is easy to interpret, fits into clinical practice, and is meaningful for therapeutic decision-making. In addition, AI-assisted screening was limited to the abstract level, which may have excluded relevant studies whose visualization contributions are detailed primarily in the full text. This trade-off was accepted given the design-oriented scope of the synthesis, but a broader, full-text-based review would strengthen future iterations of this work.

Second, the prototype demonstration focuses on a selected set of kinematic metrics commonly reported in prior literature. While these metrics provide a representative foundation, incorporating alternative measures of smoothness, coordination, and efficiency may enhance therapist interpretation. Future extensions may expand the metric set and explore alternative visual encodings to support diverse clinical reasoning strategies. Additionally, further investigations are needed to assess how different metric combinations influence cognitive load and decision-making clarity.

Third, the visualization design was demonstrated using pre-recorded motion data rather than real-time rehabilitation sessions. Consequently, contextual factors such as therapist–patient interaction, time constraints, and adaptive decision-making were not examined. Future research may evaluate the visualization system within live or simulated clinical workflows to investigate how visualization structures support dynamic decision-making and iterative treatment planning.

Building on prior research-oriented tool development (Latif & Georgiev, 2025), subsequent work may integrate computational analysis capabilities with therapist-focused visualization structures to explore hybrid systems that support both research and clinical applications. Future work should involve long-term testing in real clinical settings, with iterative refinements to evaluate stability, adaptability, and practical usability.

8 Conclusion

This study introduces a therapist-focused visualization design for upper-limb kinematic data, formulated by integrating insights from a focused mini-review with an examination of 3D movement data structure. The study analyzed existing systems to identify common visualization approaches, frequently used kinematic metrics, and limitations such as fragmented designs and limited support for interpretation. These findings guided the development of a coordinated visualization structure that connects therapist-centered needs, structured data processing, and integrated visual components.

The prototype shows how spatial, temporal, and quantitative information can be combined in a single dashboard to support a structured understanding of upper-limb rehabilitation data. Instead of introducing new kinematic metrics, the main contribution lies in reorganizing existing visualization techniques into a coordinated design focused on therapists' needs, making movement performance easier to understand in clinical practice.

This study illustrates the necessity of synchronizing visualization systems with clinical interpretive procedures in the field of healthcare design. It establishes a design foundation for future co-design efforts and empirical studies focused on developing more human-centered digital health tools for rehabilitation.

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