El Hajj et al, Gerontechnology (2026) 25:4
https://doi.org/10.4017/gt.2026.25.4.1683.7

Understanding the usability of digital technologies in home-based neurorehabilitation: a realist review

Nay El Hajj[a,b], Dahlia Kairy[a,b], Quan Nha Hong[a,b], Fatima Zeyour[b], Claude Vincent[c,d], Aliki Thomas[b,e], Sara Ahmed[b,e], Nathalie Bier[a,f], Claudine Auger[a,b,]*

[a]School of rehabilitation, Université de Montréal, Canada; [b]Centre for Interdisciplinary Research in Rehabilitation of Greater Montreal (CRIR), Canada; [c]Rehabilitation department, Université Laval, Canada; [d]Centre for interdisciplinary research in rehabilitation and social integration (Cirris), Canada; [e]School of Physical and Occupational Therapy, McGill University, Canada; [f]Centre de recherche de l'Institut universitaire de gériatrie de Montréal (CRIUGM), Canada

**Corresponding author: claudine.auger@umontreal.ca*

Abstract

Introduction: Digital technologies have the potential to transform home-based neurorehabilitation by improving access to care and enabling intensive therapy. However, the noticeable decrease in adherence to technologies when comparing clinical to home settings suggests critical usability challenges in terms of effectiveness, efficiency, and satisfaction that are not yet fully understood.

Objective: Understand how, why, and under what circumstances are digital technologies usable for home-based neurorehabilitation.

Methods: Following Pawson et al. (2005) methodology and RAMESES I standards, a five stage realist review was conducted: (1) developing an initial theory from existing theoretical frameworks; (2) systematically searching the literature from 2015 to 2023; (3) selecting the studies; (4) extracting Context-Mechanism-Outcome (CMO) configurations; and (5) conducting theory-driven analysis to revise, validate, or eliminate elements from the initial theory leading to a refined middle-range theory.

Results: Of 4,708 records, 134 articles were retained. A total of 379 extracted CMOs were analyzed to refine the initial theory into 9 key mechanisms that can be activated or inhibited by 33 contextual factors, influencing home usability for people with neurological conditions, their caregivers, and health professionals.

Conclusion: The proposed middle-range theory enhances our understanding of digital technology usability and translates theory into practice to guide home neurorehabilitation solutions.

Keywords: Digital technology, neurological rehabilitation, home environment, review

Introduction

With the rapid rise of digital health, the use of digital technologies has become a key application, offering a wide range of evolving solutions to support the needs of healthcare systems (World Health Organization, 2019). Digital rehabilitation refers to "the use of digital technologies (by rehabilitation professionals or self-driven clients) as part of the rehabilitation process in its different phases (diagnostic/assessment, goal setting, intervention, monitoring, and evaluation)" (Arntz et al., 2023).

More than 3 billion people worldwide are affected by neurological conditions that are now considered the leading cause of overall disability worldwide, accounting for 443 million Disability-Adjusted Life Years in 2021 (DALYs; quantifying years of life lost due to premature death and years lived with disability) (GBD 2021 Nervous System Disorders Collaborators, 2024). This high prevalence highlights the importance of neurorehabilitation, which is increasingly supported by evidence-based interventions grounded in neuroplasticity and functional recovery principles (Khan et al., 2017). Neuorehabilitation plays a vital role in enhancing the quality of life and autonomy of individuals across different age groups, especially older adults who may face various challenges such as mobility issues, comorbidities, and the need for long-term care (Dumurgier & Tzourio, 2020; McClure & Leah, 2021). Neurorehabilitation typically involves repeated in-person sessions offered in healthcare facilities, which can be burdensome for patients and their caregivers (Bartolo et al., 2010; Lambercy et al., 2021). Advances in digital technologies are transforming the rehabilitation field by enlarging the scope of rehabilitation contexts through remote, personalized, and continuous care options, including from patients' homes (Martinez-Martin & Cazorla, 2019). The effectiveness of neurorehabilitation is significantly enhanced by ensuring a high intensity of interventions (Daly et al., 2019; Königs et al., 2018), to which digital technologies may contribute by potentially enabling more frequent therapy sessions and delivering engaging home-based interventions (Chen et al., 2019; Chen et al., 2020). Thus, digital technologies can play an essential role in maximizing the benefits of neurorehabilitation for adults and older adults.

Despite the potential of digital technologies for neurorehabilitation, understanding their usability within home environments remains a complex issue. In fact, the home setting often poses practical challenges, including user technical proficiency, mainly when patients must operate the system, as well as space constraints and the need for family involvement (Chen et al., 2019). In addition, the COVID-19 pandemic revealed the fragility of hospital-centric neurorehabilitation; a viable shift to home-based care therefore depends on technologies that are safe and user-friendly, portable, robust, and scalable, with usability emerging as a decisive determinant of adoption (Lambercy et al., 2021). Based on the ISO9241-11:2018 definition (ISO, 2018), usability encompasses various dimensions such as effectiveness (results demonstrated), efficiency (resources required), and user satisfaction (needs and expectations fulfilled), which are influenced by numerous contextual factors and individual characteristics. Although understanding these influences is crucial for developing technologies that are effective, efficient and satisfying for users, determining whether a technology is usable remains challenging given the complexity of bringing digital neurorehabilitation to the home setting.

When it comes to facilitating autonomy in one's home and preventing institutionalization, studies often focus on what works. Still, they fall short of explaining the mechanisms of action underlying the interventions' effectiveness (Gaugler et al., 2023). This underscores the need for research that delves into 'how' and 'why' complex interventions such as home-based digital neurorehabilitation work in particular contexts. The research question guiding this review is: How, why, and under what circumstances/contexts are digital technologies usable for home-based neurorehabilitation?

Methods

We conducted a realist review, guided by the five steps outlined by Pawson et al. (2005) and following the RAMESES publication standards (Wong et al., 2013). The project received ethical approval (MP-50-2024-2020) in March 2024 to recruit an expert advisory group from the Research Ethics Board in Rehabilitation and Physical Disability (CER-RDP), CIUSSS du Centre-Sud-de-l'Île-de-Montréal (CCSMTL), Canada. The review was registered with PROSPERO (CRD42024533432) in April 2024. As the review progressed, we refined our data synthesis method to accommodate the large number of extracted materials as described below.

A realist review is particularly suitable for this research question because it emphasizes understanding the specific contextual factors and underlying mechanisms that influence intervention effectiveness (Pawson et al., 2005). By using the context-mechanism-outcome (CMO) configuration [context (C) + mechanism (M) = outcome (O)] (De Weger et al., 2020), this approach enables us to explain how the characteristics of the home context (C) activate specific mechanisms (M) to generate certain outcomes regarding the usability of technologies (O). Aggregating CMO configurations across cases reveals recurrent outcome patterns linked to specific contexts and mechanisms; these recurrent patterns, defined here as demi-regularities, provide the basis for refining middle-range program theory (Lawson, 1997; Pawson, 2006). Given the multidimensional character of usability concepts, the diversity of digital technologies, and the intricate nature of neurological conditions, a realist methodology is uniquely positioned to capture these dynamic relationships effectively.

Expert advisory group involvement

In this realist review, an advisory group of rehabilitation researchers (occupational and physical therapy) was established within the network of the principal investigators (CA, DK) based on their expertise in rehabilitation technologies or realist methodologies. Recognising that involving advisory groups in realist reviews is an established and recommended practice (Power et al., 2024), their primary role was to provide ongoing validation and feedback throughout the review process.

Step 1: Overview of the literature

We started by defining the scope of the review through creating an initial program theory, a basic understanding of how home-based digital neurorehabilitation functions that forms the foundation for all later analyses. To build this theory, we used four complementary strategies: concept definition, iterative searching, model integration, and expert advisory group input (Booth et al., 2020; Shearn et al., 2017). We described technology outcomes (O) using the usability definitions of the International Organization for Standardization ISO 9241-11: 2018 guidelines (ISO, 2018) (see *Table 1*). For descriptive purposes, we applied the classification of digital rehabilitation

Table 1. Definitions supporting the scoping of the literature

Terms	Definitions
Realist Review (Pawson et al., 2005)	"A theory-driven strategy for synthesizing research. It seeks to unpack the mechanism of how complex programs work (or why they fail) in particular contexts and settings."
|Context (Duddy & Wong, 2023)	"Any condition that triggers and/or modifies the behaviour of a mechanism. Context refers to the important feature(s) of the circumstances in which an intervention 'works' (or a phenomenon happens) which 'trigger' the mechanisms that generate outcomes. Changes in context over time or in different settings will affect whether and which mechanisms are in operation."
|Mechanism (Duddy & Wong, 2023)	"The underlying process by which outcomes are caused. Mechanisms are usually descriptions of the tendencies, reasoning and behaviour of agents involved in a process or users in an intervention and their response to the important context(s) in which they exist. Mechanisms are not the same as 'variables or correlates' that are associated with particular outcomes; instead, they offer an explanation for why and how observed outcomes happen."
|Outcome (Duddy & Wong, 2023)	Any result of the intervention, influenced by the interaction of context and mechanism, including both proximal (process) and distal (ultimate) outcomes. Intended and unintended effects are considered to provide a comprehensive understanding of an intervention's impact.
Demi-regularities (Lawson, 1997)	"A partial event regularity which prima facie indicates the occasional, but less than universal, actualization of a mechanism or tendency, over a definite region of time-space."
Usability (ISO, 2018)	"The degree to which a system, product, or service can be used by specified users to achieve defined goals with effectiveness, efficiency, and satisfaction in a specified context of use."
|Effectiveness (ISO, 2018)	"The precision and degree of completion with which the user achieves specified goals."
|Efficiency (ISO, 2018)	"The ratio between the resources used and the results obtained."
|Satisfaction (ISO, 2018)	"The degree to which the physical, cognitive, and emotional reactions of the user resulting from the use of a system, product, or service meet the user's needs and expectations."
Digital rehabilitation (Arntz et al., 2023; Kidritsch et al., 2023)	"Digital Rehabilitation (DR) is the use of digital technologies (by rehabilitation professionals or self-driven clients) as part of the rehabilitation process in its different phases (diagnostic/assessment, goal setting, intervention, monitoring, evaluation). Digital Rehabilitation aims to optimize functioning and reduce disability of individuals in interaction with their environment. Therefore, Digital Rehabilitation has a strong link with the empowerment of individuals and communities. This can include, but is not limited to, the use of tele- and remote rehabilitation applications and services, automatic services, robot-assisted technologies, wearable physical activity trackers, emails, video, speech, and text messaging solutions."

technologies proposed by Arntz et al. (2023), with definitions established through a Delphi consensus process (Kidritsch et al., 2023).

To inform the initial program theory on the usability of technologies at home, the first author conducted a Google Scholar scoping search, consistent with evidence that broad web searching can be more efficient than using academic databases at this stage of program theory development (Coleman et al., 2020). This exploratory search involved terms such as "framework," "theories," "models," "concepts," "systems," "approaches," "usability," or "technology." This list of potential frameworks and models related to our research question was then supplemented by the expert advisory group recommendations. Subsequently, we conducted a purposive search in Google Scholar, targeting each identified framework or model to determine its potential contribution to our initial program theory. Since no single framework or model could fully explain the complexity of digital technology usability, multiple theoretical foundations were examined before narrowing down to the Human Activity Assistive Technology (HAAT) model (Cook et al., 2020), the Technology Acceptance Model (TAM3) (Venkatesh & Bala, 2008), and Roger's theory of diffusion (Rogers, 2003). Based on these frameworks, the initial program theory was developed (Supplementary file 1: Initial program theory).

Step 2: Searching for evidence

As research on digital technologies in home settings peaked in 2015–2016 (Giraldo et al., 2025), we limited inclusion to studies published from 2015 to 2023. We searched MEDLINE, Embase, CINAHL, and Web of Science, consistent with recommended database coverage for optimal retrieval (Bramer et al., 2017). The search strategy was adapted for each database with the support of a university librarian (see Supplementary file 2: Search strategy). Additional steps ensured the identification of relevant evidence from a wide range of sources, including backward and forward citation searches of included papers, consulting specific websites of the technologies when available, and seeking input from the expert advisory group. For instance, articles that described a technology in more detail on the developer's website were checked to understand how the device worked. By also examining related resources and article protocols that described methods or technologies in more detail, we ensured a thorough understanding of the neurorehabilitation technological intervention.

Table 2 presents our inclusion and exclusion criteria, which were intentionally kept broad to align with the principles of realist reviews that embrace a wide range of primary data to contribute to theory building (Pawson et al., 2005). We limited our selection to motor rehabilitation to ensure actionability, applicability and specificity

Table 2. Inclusion and exclusion criteria

Article selection	
Inclusion criteria	
P – Population	Neurological conditions primarily affecting the motor component
I – Intervention	Digital technologies for neurorehabilitation in home setting
C – Comparator	N/A
O – Outcome	Effectiveness, efficiency, satisfaction based on ISO9241-11 norm (ISO, 2018)
Characteristics of studies	
- Published between 2015 and 2023	
- No restriction on types of primary studies included	
Exclusion criteria	
- Documents in languages other than French or English	
- Neurological conditions not primarily affecting the motor component	
- Non-residential context (hospitals, community centers, clinics, etc.)	
- Non-digital technologies, not targeting the motor component, involving invasive procedures, or just describing prototypes	
- No assessment of the usability of the technology, no description of results, or insufficient description to detect CMO elements (context-mechanism-outcome)	

of our final theory, without restricting neurological conditions or technology types.

Step 3: Selecting studies

EndNote 21 software was used to manage the bibliographic search, and article selection was then carried out using the Covidence online software. Two independent reviewers with graduate training in the rehabilitation field (NEH, with two research assistants, ELM or KVSM) independently screened the articles based on the title and abstract, followed by a full-text review. In the event of disagreement after discussion among the reviewers, a third reviewer (CA or DK) helped reach consensus. Each selected article could be complemented with additional resources identified in the article, such as the technology's website or a protocol article. When applicable, these resources were added as complementary materials rather than as independent sources of information, since their main goal was to support our understanding of the main article.

In line with the RAMESES standards (Wong et al., 2013), articles were assessed for relevance and rigour. Relevance was determined by an article's contribution to theory building or testing through its discussion of context, mechanisms, or outcomes related to the usability of home-based technologies for neurological conditions. Rigour was assessed by evaluating the trustworthiness of the data and the strength of the theoretical explanations in developing a plausible middle-range theory. Trustworthiness required clearly reported methods and corroboration from multiple documentaries and/or non-documentary sources, such as experts' insight (Wong, 2018). A sample (10%) of sources was reviewed with the expert advisory group for consistency. For the remainder, relevance and rigour were discussed between the two independent reviewers, with CA or DK consulted to reach consensus.

Step 4: Extracting data

The study descriptions were independently extracted by two reviewers (NEH, with FZ or two research assistants JN or KR) using Covidence, including the following elements: study title, year of publication, country of conduct, study objectives, technologies addressed, settings (e.g., home exclusively, home and clinic), methods, target populations, key findings, and usability dimensions (effectiveness, efficiency, satisfaction). CMO configurations were extracted using NVivo 14. The annotation function was used to rephrase CMO configurations based on an initial understanding of the causal mechanisms explaining each article's results, and to add reflections while reading the articles. This process maintained the logic and coherence described in the article and helped synthesize the extracted data to test the initial program theory (Peters, 2024). Each CMO included in the synthesis resulted from a double independent extraction (NEH, with FZ or two research assistants, JN or KR). The paired extractions were compared, discordant elements were removed, complementary elements merged, and the resulting CMOs were retained for each article.

Step 5: Synthesising the evidence

A realist-analytical approach (Pawson & Tilley, 1997) was used to explain CMO patterns and to refine the initial program theory (*Figure 1*). We first identified key mechanisms: CMOs sharing similar underlying processes were mapped deductively to a component of the initial program theory. As the analysis progressed, well-tested components were kept, unsupported components were dismissed, overlapping components were merged, and new mechanisms were added using abductive inference when CMOs did not fit.

Once key mechanisms were defined, we examined the CMOs regrouped under each mechanism to identify recurrent contextual factors that could activate or inhibit them. Tracing recurring patterns of associated mechanisms and contextual factors revealed demi-regularities, providing a more comprehensive understanding of observed outcomes and informing refinement of the initial program theory into a middle-range program theory. The synthesis was iterative and

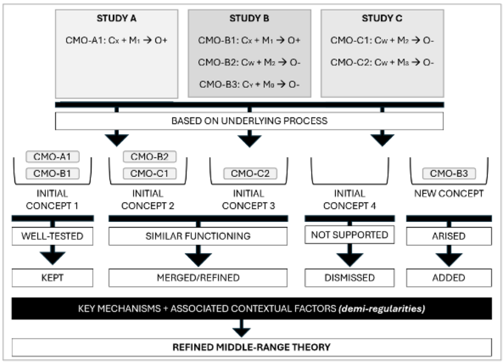

Figure 1. From CMO Configurations to Demi-Regularities: Realist Synthesis Workflow for Theory Refinement. $C_{X/Y/W}$: Contexts – $M_{0/1/2/3}$: Mechanisms – $O_{+/-}$: Outcomes – CMO: Context-Mechanism-Outcome

involved the expert advisory group for assessing empirical support, adjudicating between competing explanations, applying the same theory in different situations, and comparing the findings with practical experiences (Pawson et al., 2005).

Results

A total of 6791 records were identified, and 134 articles were retained for analysis (*Figure 2*).

Study characteristics

Nine out of the 134 articles were multi-country studies, for a total of 145 countries in which studies were conducted, mostly in Europe (n=60; 41.4%) and North America (n=59; 40.7%), followed by Asia (n=19; 13.1%), Oceania (n=5; 3.4%), South America (n=1; 0.7%), and Africa (n=1; 0.7%). Although the review spanned 8 years, most studies were published during the last three years (2020-2023, n=84; 62.7%). Based on Arntz et al. (2023) classification, the most common digital technologies studied were digital and mobile apps (n=70; 52.2%) and sensors (n=66; 49.3%), as they were frequently integrated or combined with other devices for data

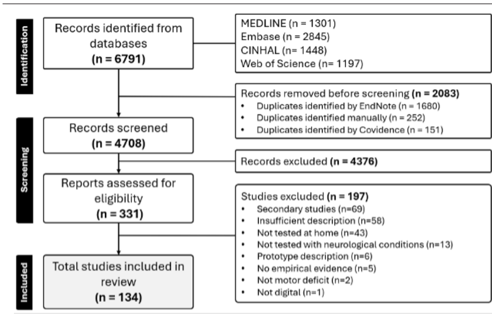

Figure 2. Flow diagram of the realist review on home-based digital rehabilitation

collection and interfaces, followed by gamification (n=45; 33.6%), virtual and augmented reality (n=28; 20.9%), robotics and brain-computer interfaces (n=27; 20.1%), AI and machine learning (n=3; 2.2%), and Internet of Things (n=1; 0.7%). Additional details and the reference list of the retained articles are provided in Supplementary file 3: Description of included articles.

Main findings

The initial program theory comprised 23 elements across four domains: person, technology, activity, and context (see Supplementary file 3: Description of included articles for details). It posited that, in a home context during rehabilitation activities, usability arises from the interaction between people and technology and may be selectively favourable relative to competing options. After data extraction and synthesis, a total of 379 extracted CMO configurations were retained and classified under pattern-matching 9 key mechanisms, each with 33 associated contextual factors that reoriented the theory (see *Table 3*). The detailed list of CMO configurations and additional explanations can be found in Supplementary file 4: List of Context-Mechanism-Outcome configurations regrouped under each mechanism.

Our middle-range theory is composed of a set of demi-regularities (recurring patterns) represented by 9 key mechanisms and 18 associated contextual factors. Each demi-regularity links a mechanism with its associated contextual factors and specifies how this interaction influences usability. The nine mechanisms are (1) likability, (2) perceived ease of use, (3) oservability, (4) adaptability, (5) cultural fit, (6) sense of control, (7) quality of output, (8) resources, and (9) relative advantage. Our middle-range theory supports that usability outcomes can be positively influenced when a digital technology is (1) enjoyable, (2) easy to use, (3) provides observable outcomes, (4) adapts to user needs, (5) is aligned with the users' culture, (6) provides a sense of control, (7) produces reliable output, and (8) is accessible with available resources. Ultimately, the preceding mechanisms will influence the overall (9) perceived advantage or disadvantage over other rehabilitation approaches depending on the balance between the three usability pillars (effectiveness, efficiency, satisfaction). These mechanisms could also have negative impacts based on identified contextual factors, which serve as practical insights into the circumstances that lead to undesired outcomes. In the next paragraphs, the key mechanisms are defined, as well as how they operate through their associated contextual factors, with "users" referring to participants, caregivers, or therapists.

Table 3. Key mechanisms and associated contextual factors impacting usability outcomes in home-based digital neurorehabilitation

C.: Context – CMO: Context-Mechanism-Outcome
+: At least one CMO has a positive, none has a negative influence on outcomes.
±: CMOs show both positive and negative influences on outcomes.
–: All CMOs have a negative influence on outcomes.

		Outcome		
		Efficiency	**Effectiveness**	**Satisfaction**
Mechanism: Observability				
Context	Provide real-time feedback cues		±	±
	Track activity continuously	-	+	±
	Demonstrate visible transfer to activity and participation		±	+
	Display quantified progress metrics		+	±
	Model through action observation		+	+
Mechanism: Cultural fit				
C.	Match with users' technological familiarity	+	+	+
	Align intervention to culture and language		±	+
	Design devices for comfort and discretion		±	±
	Address professional and user preconceptions	-	-	-
Mechanism: Quality of output				
C.	Ensure reliable technology performance	-	±	±
	Deliver accurate automated measurement and data transfer	+	±	
	Provide human touch and realistic support	-	±	+
Mechanism: Adaptability				
C.	Tailor challenge and content		±	±
	Provide multi-channel support	+	+	±
	Enable flexible scheduling and reminders	-	±	±
	Accommodate device-related constraints	-	±	±
	Align practice with daily activities		±	+
Mechanism: Perceived ease of use				
C.	Design intuitive, minimal interfaces	±	±	±
	Simplify setup and device handling	±	±	±
	Support learning with training and guidance	+	±	±
Mechanism: Sense of control				
C.	Prioritize user safety	+	±	+
	Provide privacy controls		-	±
	Offer adequate supervision	±	±	
Mechanism: Likability				
C.	Foster social interaction		+	±
	Deliver fun gamified experiences		±	±
	Promote immersion in practice		+	+
	Minimize user burden and discomfort	+	±	±
Mechanism: Resources				
C.	Reduce on-site requirements	±		+
	Streamline troubleshooting	±	+	+
	Minimize device footprint	±	±	-
	Maximize functional uptime	±		-
Mechanism 9: Relative advantage				
C.	Emphasize standout benefits	+	±	+
	Avoid potential turn-offs	+	±	±

Observability

Observability is the degree to which a technology makes its results visible and tangible to users and observers. We identified five contexts that trigger this mechanism.

Provide real-time feedback cues: the capacity to issue immediate visual, auditory, or somatosensory responses to user actions can increase performance awareness and enable direct movement adjustment. For example, live electromyography (EMG) visualization in a stroke-rehabilitation home program deepened engagement and accelerated motor recovery (Marin-Pardo et al., 2022). Yet, poorly tuned or ambiguous feedback led to frustration and lowered satisfaction.

Display quantified progress metrics: translating user performance into concrete, visually presented data makes even small gains visible, fostering confidence, and making goal setting more precise. Excessive complexity, on the other hand, can create cognitive load and undermine usability. For example, clinicians experienced cognitive burden when intricate graphs became difficult to interpret (Tyagi et al., 2018).

Track activity continuously: capturing behaviour in real time or across extended time periods and reflecting it to users can strengthen self-awareness, accountability, and engagement, thereby improving outcomes. However, when status cues such as battery life or sensor status indicators were hidden, it raised uncertainty about whether data were being captured, leading users to seek unnecessary technical support (Demers et al., 2023; van den Bergh et al., 2023).

Model through action observation: presenting movement demonstrations, either performed by someone else or recorded from the user, makes desired actions explicit, facilitates imitation and reflection on personal performance. For example, users who viewed short self-modelled gait videos became acutely aware of their movement patterns. The brief embarrassment or shock this provoked motivated them to improve and fueled a strong interest in continuing the training (Goh et al., 2021).

Demonstrate visible transfer to activity and participation: ensuring that motor gains become evident in everyday tasks empowers users to repeat and extend those gains beyond formal sessions, thereby enhancing effectiveness and satisfaction. Yet overly specific or isolated practice may fail to generalise, leaving users unsure of the intervention's practical value. For example, participants who completed narrowly focused virtual reality drills achieved improvements only in the practised motions, with no observable transfer to daily activities (Kamm et al., 2023).

Cultural fit
By cultural fit, we mean the extent to which a technology aligns with a user's cultural values, norms, experiences, and daily practices. We identified four contexts that activate this mechanism.

Match with users' technological familiarity: When intervention delivery mirrors established digital habits of its intended users, allowing minimal cognitive effort to navigate, it allows a better integration of therapeutic tasks into routine life, thus achieving greater effectiveness, satisfaction, and efficiency. For example, smartphone-owning participants strongly accepted an app-based home exercise program due to their familiarity with the device (Kim & Kim, 2022).

Align the intervention to culture and language: Consider the cultural context that shapes how users communicate, learn, and assign roles at home, and make instructions clear and intuitive, so users feel the service is meant for them, boosting effectiveness, satisfaction, and efficiency. Low alignment can make the tool seem irrelevant or hard to follow, diminishing motivation and weakening effectiveness. For example, in a context where the cultural norm for the participant is to adopt the "sick role" and depend on caregivers, they judged telerehabilitation unnecessary, and they disengaged (Tyagi et al., 2018).
Design devices for comfort and discretion: Designing modalities to be non-irritating, and socially inconspicuous promotes continuous use across settings, securing richer data and sustained engagement. However, devices that are hard to socially fade into the background can trigger self-consciousness and discomfort, prompt removal and may interrupt monitoring. For example, some individuals preferred home telerehabilitation because it reduced attention to visible disability (van den Bergh et al., 2023).

Address preconceptions and expectations: Users' prior representation of how rehabilitation should be delivered might misalign with digital solutions, which can trigger disappointment, erode trust, and even prompt withdrawal. For example, a participant in a structured therapist-guided videoconference withdrew when the fixed guidance did not match her expectations for a self-directed approach (Zhang et al., 2022).

Quality of output
Quality of output refers to the degree to which a technology performs its intended functions smoothly and consistently, without errors or interruptions. We identified three contexts that trigger this mechanism.

Ensure reliable technology performance: The capacity to maintain steady performance under normal operating variations with accessible support preserves continuity and confidence. However, recurring glitches and weak connectivity interrupt sessions and prolong troubleshooting, creating reliance on others. For example, when a telerehabilitation platform ran smoothly, people used it longer and felt assured, whereas bugs provoked frustration and lower satisfaction (Donnelly et al., 2023).

Deliver accurate automated measurement: Capturing metrics effortlessly can provide records that are trustworthy and timely but also help in rapidly identifying and resolving system errors. However, home environments can complicate capture, even weaken measurement quality and reliability. For example, home environment exposed users to real-life obstacles, slopes, and turnings which reduced concordance between sensor estimates and clinical benchmarks, producing less accurate readings (Atrsaei et al., 2021).

Provide human touch and realistic support: Combining human judgment with data-driven tools grounds interpretation and keeps goals credible, supporting effectiveness, satisfaction, and efficiency. However, securing such oversight can be resource-intensive and slow. For example, careful clinician review of home video produced a precise estimate of exercise time, yet the analysis took hours per participant, lowering efficiency and making this approach not viable despite greater confidence in results (Levy et al., 2021).

Adaptability
By adaptability, we mean the degree to which a user perceives that a technology is compatible with their needs and offers tailored support for

their individual situation. We identified five contexts that trigger this mechanism.

Tailor challenge and content: Continuous alignment of goals, calibration, and feedback with users' abilities, which are constantly changing in neurological conditions, keeps demands proportionate and training effective. However, when adaptation lags or personalization is missing, tasks misfit capacity, the 'just-right challenge' is missing, leading to inconsistent practice. For example, commercially available exergames with no therapeutic personalization limited movement variety and were linked to limited improvement in occupational performance over time (Adie et al., 2017).

Provide multi-channel support: Diverse avenues of assistance let each user access guidance that suits their circumstances, resolving issues quickly and keeping operations steady. However, reliance on a single uniform source of support might be perceived as insufficient by users. For example, combining education, caregiver involvement, and flexible contact with therapists provided tailored support that maintained correct usage and preserved gains (Epalte et al., 2023).

Accommodate device-related constraints: The ability to work within a device's physical, mechanical, and interface limits helps maintain consistent usage across varied user needs. For example, offering glove sizes that accommodated tight or atypical hands allowed for a better fit and more effective task execution (Maddahi et al., 2021). However, when the adjustable range is reached and the mismatch cannot be resolved through adjustment, involving assistance or considering a different solution becomes necessary, particularly in cases of more severe impairment.
Enable flexible scheduling and reminders: The ability to let users engage with technology at times that are personally convenient supports integration into daily routines and encourages home use. However, without some structure or shared expectations, competing obligations, especially for those with complex schedules, can interfere with and reduce overall engagement. For example, fully flexible home training without set times led many to prioritize other tasks, producing lower use than planned over six weeks (Rozevink et al., 2021).

Align practice with daily activities: Embedding practice within meaningful, real-world tasks encourages regular engagement and reinforces continuity between training and daily function. For instance, using the motor-assisted glove during daily activities rather than isolated exercises made integration easier and improved adherence and satisfaction at home (Osuagwu et al., 2020). Furthermore, when activities remain abstract or disconnected from everyday routines, they may feel less useful, reducing motivation and limiting carryover.

Perceived ease of use
Perceived ease of use is the extent to which a user perceives that a technology minimizes unnecessary complexity and effort, fosters confidence in their ability to perform intended tasks, and perceives that it enables mastery of its function. We identified three contexts that trigger this mechanism.

Design intuitive, minimal interfaces: While unnecessary elements increase decision burden and reduce engagement, structured interaction pathways that limit cognitive branching reduce mental strain and boost confidence. For instance, when the interface offered a clear layout and straightforward progress feedback, users appreciated ease of operation. However, adding features increased complexity, overwhelming those with limited digital skills and lowering their satisfaction (van den Bergh et al., 2023).

Simplify setup and device handling: By reducing the work required to prepare or operate a system, users can devote their time and energy to more meaningful activities rather than logistical tasks, providing a welcoming, easy experience. For example, when preparation and assessment time were minimal, users spent most of each session on active training, thus increasing therapy intensity and efficiency (Wittmann et al., 2016). If setup becomes a source of friction rather than supporting recovery, it interrupts the engagement flow, creates challenges for users and reduces the perceived value using the technology.
Support learning with training and guidance: Ongoing exposure and instructional support allow users to build the understanding and confidence needed for effective engagement. In contrast, limited guidance can leave critical knowledge gaps. For example, therapists receiving only brief early exposure to a system struggled to gain confidence in effectively matching activities to participant needs (Valdes et al., 2018).

Sense of control
Having a sense of control refers to how much a user perceives that using a technology is voluntary and that they have the power to maintain their personal boundaries and reduce potential harm. We identified three contexts that activate this mechanism.

Prioritize user safety: When potential hazards are anticipated and mitigated, users feel empowered to engage without fearing harm that could worsen outcomes. Without comprehensive safeguards, unseen risks can cause injury or anxiety, affecting trust in neurorehabilitation. For example, failure to instruct safe neck movement in an augmented reality program led to a serious adverse event, turning an innocuous-like movement into serious harmful risk (Lee et al., 2023).

Provide privacy controls: Empowering users to decide what data is captured and shared strengthens their sense of agency and protects personal boundaries. The absence of these controls exposes users to vulnerability and worries about unwanted disclosure, leading to self-consciousness and reduced willingness to participate. For example, when participants feared that the camera might record confidential details or unconsenting bystanders' faces, they experienced worries and were hesitant to use the system (Bandini et al., 2021).

Offer adequate supervision: When oversight misaligns with users' needs, unnecessary monitoring inefficiently consumes time and effort, while lack of support – when needed –may bring worry about harm risk and deteriorate trust. Providing support calibrated to individual risk ensures safety while preserving autonomy. For example, caregivers' involvement during videoconference sessions considering participant's impairment severity offset motor and cognitive limitations, and ensured safety (O'Neil et al., 2023).

Likability

Likability is defined as the extent to which a user perceives their interactions with technology as fun and enjoyable, while feeling little apprehension. We identified four contexts that activate this mechanism.

Foster social interaction: Designing practice sessions around interacting with others makes participation feel friendly and fun, supporting enjoyment and smoother performance. For example, therapist videoconferences and family encouragement helped reduce isolation and strengthen connections, maintaining emotional well being and motivation to keep going (Alagumoorthi et al., 2022; Standen et al., 2015). However, when these social opportunities are scarce or absent, external encouragement and support needed to stay motivated decrease, leading to shorter practice times and less satisfaction and overall improvement.

Deliver fun gamified experiences: Designing tasks as game-like challenges with built-in progression and rewards helps turn neurorehabilitation into a playful activity, encouraging users to practice more and with enjoyment. However, when games are repetitive, too easy, and mistakes have no consequences, users may become bored, and focus shifts to quick completion over quality, lowering satisfaction and limiting gains. For example, when exergames lacked strict accuracy demands and penalties, effort shifted toward speed, leading to faster movement but poorer precision (Allen et al., 2017).

Promote immersion in practice: Creating activities that fully capture attention and sustain focus makes practice feel absorbing and easy, encouraging playful engagement and steady performance. For example, an immersive virtual reality environment reduced distractions and helped users concentrate on learning movement strategies, which improved their capacity to engage effectively with the intervention (Goh et al., 2021).
Minimize user burden and discomfort: When something feels heavy, awkward, or causes strain or irritation, it can gradually create uneasiness that makes the experience harder to tolerate, reducing satisfaction and even leading to intentional avoidance. Even when the experience isn't especially enjoyable, the absence of discomfort remains a basic condition for it to feel acceptable or likable. For example, a sensor sewn into regular clothing was described as comfortable and unobtrusive, and users wore it for two days without hesitation (Taylor-Piliae et al., 2016).

Resources

Resources refer to the degree to which a technology requires time, human effort, funds, and materials that are consumed and not reusable. We identified four contexts that trigger this mechanism.

Reduce on-site requirements: When physical presence is no longer a condition for participation, logistical demands are reduced and limited resources are conserved or reallocated more efficiently. For instance, replacing home visits with scheduled teleconsultations shifted staff travel to IT support and device amortization, keeping care costs virtually identical (Durufle et al., 2023). If effort continues to rely on repeated travel, then time and funds are consumed in ways that are hard to recover or repurpose.

Streamline troubleshooting: When resolution is timely and predictable, effort is conserved and users experience fewer interruptions, increasing satisfaction while reducing reliance on repeated inefficient interventions. In the absence of adequate troubleshooting, users might postpone or refrain from requesting assistance, which can result in minor problems consuming more time and resources than necessary. For instance, when a clear introduction to the assigned support resource was lacking, users experienced uncertainty regarding whom to approach, which caused reluctance in seeking help and subsequently delayed the resolution of technical issues (Valdes et al., 2018).

Minimize device footprint: When physical demands are low and space does not need to be actively reconfigured, integration into daily life becomes easier, allowing effort to be preserved and the experience to be more acceptable. As an example, a compact and portable system was easily accommodated at home and transported for replacement when needed, facilitating participation and an efficient use of space (Nam et al., 2021). However, if setups displace normal routines or limit movement, users might have to do compromises just to maintain access, which they may not be willingly up to.

Maximize functional uptime: System interruptions in unpredictable home settings can force users to spend time and effort during downtime, affecting efficiency and satisfaction. In certain instances, a short battery life limited the time a user could use the technology, thereby decreasing overall efficiency (Bandini et al., 2021; Bernocchi et al., 2018). Reducing these system-imposed gaps guarantees that time and focus are directed toward worthwhile goals, protecting both satisfaction and resource investment.

Relative advantage

Relative advantage refers to the degree to which a user perceives that the benefit of a technology outweighs the compromises it requires, making it preferable to other available options. We identified two contexts that trigger this mechanism.

Emphasize standout benefits: Providing distinct, observable advantages in key areas enables users to tolerate certain compromises, as the additional value is apparent. For example, the reduction of travel distance through tele-rehabilitation was perceived as more beneficial than attending clinic appointments, resulting in similar satisfaction levels without the accompanying stress (Chen et al., 2017). When technologies lack such clear benefits, the minor gains fail to justify trade-offs, and users might lean toward more familiar methods.

Avoid potential turn-offs: Sometimes it only takes a single but critical flaw to overshadow all other benefits and act as a deal-breaker. For example, limited hands-on correction by instructors in virtual classes led users to cite the loss of physical cueing as the only drawback of remote delivery (Bennett et al., 2023). Proactively reducing obstacles ensures that strong advantages remain perceivable and flaws can be overcome.

Discussion

This realist review identified how home-based digital neurorehabilitation achieves usability through 9 interlocking mechanisms shaped by 33 contextual factors, which led us to propose a middle-range theory. Our findings indicate that usability does not arise from isolated factors, but from complex pattern interactions that position a digital solution as more or less advantageous compared to other neurorehabilitation options for all potential users, such as participants, caregivers, and rehabilitation professionals.

Our realist review offers mechanism-based explanations that connect contextual factors to how digital rehabilitation technologies operate at home, providing actionable guidance for multiple audiences, such as researchers, clinicians, and technology developers. For research, the middle-range theory provides testable, context-sensitive explanations that guide study design. Unlike broader models and frameworks that often only list “what matters”, a middle-range theory explicitly specifies why and how those elements produce outcomes in particular contexts, which means it generates propositions that can be tested and refined in subsequent studies (McConnell et al., 2025). Clinicians can draw on our findings to align technology choice and implementation with users’ goals and specific home settings while anticipating barriers and facilitators. Technology developers would gain from translating the mechanisms and contextual factors into high-level design requirements and integrating them into evaluation criteria that test whether these properties operate as intended.

Previous research supports many mechanisms identified in our findings. In the scoping review by Gooch et al. (2024) on digital technologies for stroke rehabilitation, the most common behavior-change strategies included feedback-monitoring, rewards, goals-planning, and shaping knowledge. Our mechanisms such as observability, adaptability, and likability align with these patterns. However, our review provides complementary explanatory detail on how such contextual factors influence usability at home. For instance, Gooch et al. (2024) also reported that feedback and monitoring were often combined with rewards, reinforcing our findings that mechanisms often work together.

Chen et al. (2019) report several design factors of home-based rehabilitation technologies, including the importance of internal and external motivation, ease of learning, adaptability of features, and the influence of social and physical home environments. Their findings align with some of our mechanisms, notably likability, perceived ease of use, and adaptability.

Chen et al. (2019) also highlight practical challenges such as space constraints, technical issues, and the need for caregiver involvement, which are also particularly coherent with resources and sense of control mechanisms. While their synthesis focuses on identifying and categorizing these factors, our review builds on this by exploring how these elements may interact to influence usability at home.

Our results are also aligned with those of Olsen et al. (2025) who reported factors influencing the initial adoption and the sustained use of rehabilitation technologies, such as ease of learning and set-up, features that support engagement, user guidance and troubleshooting, device size and portability, fragility and maintenance, and suitability for home and community contexts. However, they introduced “healthcare ecosystem”, encompassing operational, strategic, and regulatory-funding conditions, as an additional theme to consider about sustained use, which is largely absent from our findings. This is likely due to our exclusive focus on home context where studies rarely describe the health care system, highlighting that long-term usability outcomes at home are still insufficiently studied.

As mentioned above, the proposed middle-range theory helps guide strategies to support home-based digital rehabilitation in terms of usability. However, usability alone is not enough to predict real-world adoption. For example, in Chung et al. (2025), participants found an AI conversational interface easy to use, an indicator of usability, yet this did not translate into intent to adopt, highlighting the importance of factors beyond usability such as seamless integration into routine clinical systems and workflows. When the focus shifts from usability to uptake in practice, it intersects with the broader, multifactorial challenge of digital implementation and its many existing models, some of which are criticized for listing actions without clarifying the how or why (Greenhalgh & Abimbola, 2019; Lau & Kuziemsky, 2016) (Nilsen, 2015; Wang et al., 2023; Westerlund et al., 2019). In this context, developing a middle-range theory would provide an explanatory structure to guide the operationalization of strategies, while recognizing that translating theory into action requires iterative adaptation to the context (McConnell et al., 2025).

A key strength of our review is its methodological rigour. Two independent reviewers handled study selection and data extraction, reducing bias and increasing the reliability of the synthesis. Ongoing input from an expert advisory group further anchored interpretations in the realities of home-based neurorehabilitation, enhancing relevance and applicability. Also, adopting multiple frameworks and models at the initial stage as a theoretical foundation provided a broader perspective and facilitated the identification of factors influencing the usability of digital rehabilitation.

However, there are limitations to consider. Since most included studies did not track participants over extended periods, our capacity to make strong claims about long-term usability remains limited. Many included studies excluded people with cognitive impairments, limiting transferability to neurological groups in which such impairments are common. Also, efficiency outcomes were rarely examined compared to other usability dimensions, echoing a field-wide emphasis on “what works” over “how it can work sustainably”. Emerging technologies such as artificial intelligence and the Internet of Things were under-represented (respectively 2.2% and 0.7% of our study sample), likely reflecting their more recent emergence compared to other devices. As the literature on these topics grows, our middle-range theory might need refinement. In addition, the Arntz et al. (2023) classification we used is device-oriented (what) and does not fully capture goal-oriented aspects (why) of digital neurorehabilitation which may be better covered by a generic functional classification of digital health such as the WHO classification (World Health, 2018).

Future research should include participants with cognitive deficits, evaluate usability comprehensively across the three pillars, and consider technological advancements and services. Doing so will support refining the presented usability models to be even more empirically grounded yet broadly applicable and thus well placed to inform the design and deployment of more usable solutions that overcome home-based barriers to adoption and improve usability outcomes.

The review refined a middle-range theory, shaped by 9 key mechanisms and 33 corresponding contextual factors, to be considered when developing or making decisions about the usability of digital solutions for the home setting, based on 134 references. These technologies are evolving rapidly and growing in popularity; however, additional research is needed to keep pace with advances and ensure that our findings, based on the past eight years of literature, remain applicable as the field evolves. Accordingly, future studies should prioritize field-testing this middle-range theory to refine the findings and align them with implementation outcomes in real-world home contexts.

Funding statement: This work was supported through scholarship funding by Université de Montréal, the Centre for Interdisciplinary Research in Rehabilitation of Greater Montreal (CRIR), Mitacs Accelerate and the Lindsay Rehabilitation Hospital Foundation. Also, DK, QNH and NB were supported by a Research Scholar Award from the Fonds de recherche du Québec - Santé (FRQS).

Author contributions: NeH, QNH, DK, and CA were involved in the conceptualization of the project and in all five stages of the review (steps 1-5), while also participating in expert advisory group meetings. FZ was involved in the extraction stage (step 4). AT, SA, NB and CV, were consulted in most stages (steps 1,3-5), participating in expert advisory group meetings, and reviewed the drafts. NeH drafted the article, DK and CA reviewed the initial drafts followed by revisions from all remaining authors. All authors approved the final version of the manuscript.

Patient and public involvement: Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Competing interests' statement: none

Acknowledgements: We would like to thank Virginie Paquet, university librarian, for her contribution to the search strategy; Vincent Létourneau-Desjardins for the support with qualitative data management; and the research assistants Elise Le Masson (ELM), Jeremy Nguyen (JN), Kristen Reidel (KR), and Karla Vanessa Soares Menezes (KVSM).

References

Adie, K., Schofield, C., Berrow, M., Wingham, J., Humfryes, J., Pritchard, C., James, M., & Allison, R. (2017). Does the use of Nintendo Wii SportsTM improve arm function? Trial of WiiTM in Stroke: a randomized controlled trial and economics analysis. Clinical Rehabilitation, 31(2), 173-185. https://doi.org/https://dx.doi.org/10.1177/0269215516637893

Alagumoorthi, G., D, B. J., Thirunavukarasu, S., V, R., & A, K. (2022). Effectiveness of Wii sports- based strategy training in reducing risk of falling, falls and improving quality of life in adults with idiopathic Parkinson's disease- a randomized comparative trial. Clinical Rehabilitation, 36(8), 1097-1109. https://doi.org/10.1177/02692155221089030

Allen, N. E., Song, J., Paul, S. S., Smith, S., O'Duffy, J., Schmidt, M., Love, R., Sherrington, C., & Canning, C. G. (2017). An interactive videogame for arm and hand exercise in people with Parkinson's disease: A randomized controlled trial. Parkinsonism and Related Disorders, 41, 66-72. https://doi.org/https://dx.doi.org/10.1016/j.parkreldis.2017.05.011

Arntz, A., Weber, F., Handgraaf, M., Lällä, K., Korniloff, K., Murtonen, K. P., Chichaeva, J., Kidritsch, A., Heller, M., Sakellari, E., Athanasopoulou, C., Lagiou, A., Tzonichaki, I., Salinas-Bueno, I., Martínez-Bueso, P., Velasco-Roldán, O., Schulz, R. J., & Grüneberg, C. (2023). Technologies in Home-Based Digital Rehabilitation: Scoping Review. JMIR Rehabil Assist Technol, 10, e43615. https://doi.org/10.2196/43615

Atrsaei, A., Dadashi, F., Mariani, B., Gonzenbach, R., & Aminian, K. (2021). Toward a Remote Assessment of Walking Bout and Speed: Application in Patients with Multiple Sclerosis. IEEE Journal of Biomedical and Health Informatics, 25(11), 4217-4228. https://doi.org/https://dx.doi.org/10.1109/JBHI.2021.3076707

Bandini, A., Kalsi-Ryan, S., Craven, B. C., Zariffa, J., & Hitzig, S. L. (2021). Perspectives and recommendations of individuals with tetraplegia regarding wearable cameras for monitoring hand function at home: Insights from a community-based study. Journal of Spinal Cord Medicine, 44(S1), S173-S184. https://doi.org/https://dx.doi.org/10.1080/10790268.2021.1920787

Bartolo, M., De Luca, D., Serrao, M., Sinforiani, E., Zucchella, C., & Sandrini, G. (2010). Caregivers burden and needs in community neurorehabilitation. J Rehabil Med, 42(9), 818-822. https://doi.org/10.2340/16501977-0612

Bennett, H. B., Walter, C. S., Oholendt, C. K., Coleman, K. S., & Vincenzo, J. L. (2023). Views of in-person and virtual group exercise before and during the pandemic in people with Parkinson disease. Pm & R, 15(6), 772-779. https://doi.org/https://dx.doi.org/10.1002/pmrj.12848

Bernocchi, P., Mule, C., Vanoglio, F., Taveggia, G., Luisa, A., & Scalvini, S. (2018). Home-based hand rehabilitation with a robotic glove in hemiplegic patients after stroke: a pilot feasibility study. Topics in Stroke Rehabilitation, 25(2), 114-119. https://doi.org/https://dx.doi.org/10.1080/10749357.2017.1389021

Booth, A., Briscoe, S., & Wright, J. M. (2020). The "realist search": A systematic scoping review of current practice and reporting. Res Synth Methods, 11(1), 14-35. https://doi.org/10.1002/jrsm.1386

Bramer, W. M., Rethlefsen, M. L., Kleijnen, J., & Franco, O. H. (2017). Optimal database combinations for literature searches in systematic reviews: a prospective exploratory study. Syst Rev, 6(1), 245. https://doi.org/10.1186/s13643-017-0644-y

Chen, J., Jin, W., Dong, W. S., Jin, Y., Qiao, F. L., Zhou, Y. F., & Ren, C. C. (2017). Effects of Home-based Telesupervising Rehabilitation on Physical Function for Stroke Survivors with Hemiplegia A Randomized Controlled Trial. American Journal of Physical Medicine & Rehabilitation, 96(3), 152-160. https://doi.org/10.1097/PHM.0000000000000559

Chen, Y., Abel, K. T., Janecek, J. T., Chen, Y., Zheng, K., & Cramer, S. C. (2019). Home-based technologies for stroke rehabilitation: A systematic review. Int J Med Inform, 123, 11-22. https://doi.org/10.1016/j.ijmedinf.2018.12.001

Chen, Y., Chen, Y., Zheng, K., Dodakian, L., See, J., Zhou, R., Chiu, N., Augsburger, R., McKenzie, A., & Cramer, S. C. (2020). A qualitative study on user acceptance of a home-based stroke telerehabili-

tation system. Top Stroke Rehabil, 27(2), 81-92. https://doi.org/10.1080/10749357.2019.1683792
Chung, S., Giuffrè, M., Rajashekar, N., Pu, Y., Shin, Y. E., Kresevic, S., Chan, C., Nakamura-Sakai, S., You, K., Saarinen, T., Hsiao, A., Wong, A. H., Evans, L., McCall, T., Kizilcec, R. F., Sekhon, J., Laine, L., & Shung, D. L. (2025). Usability and adoption in a randomized trial of GutGPT a GenAI tool for gastrointestinal bleeding. NPJ Digit Med, 8(1), 527. https://doi.org/10.1038/s41746-025-01896-5
Coleman, S., Wright, J. M., Nixon, J., Schoonhoven, L., Twiddy, M., & Greenhalgh, J. (2020). Searching for Programme theories for a realist evaluation: a case study comparing an academic database search and a simple Google search. BMC Medical Research Methodology, 20(1), 217. https://doi.org/10.1186/s12874-020-01084-x
Cook, A. M., Polgar, J. M., & Encarnação, P. (2020). Assistive Technologies : Principles & Practice (Fifth Edition ed.). Mosby. https://doi.org/https://doi.org/10.1016/B978-0-323-52338-7.00003-2
Daly, J. J., McCabe, J. P., Holcomb, J., Monkiewicz, M., Gansen, J., & Pundik, S. (2019). Long-Dose Intensive Therapy Is Necessary for Strong, Clinically Significant, Upper Limb Functional Gains and Retained Gains in Severe/Moderate Chronic Stroke. Neurorehabil Neural Repair, 33(7), 523-537. https://doi.org/10.1177/1545968319846120
De Weger, E., Van Vooren, N., Wong, G., Dalkin, S., Marchal, B., Drewes, H., & Baan, C. (2020). What's in a realist configuration? Deciding which causal configurations to use, how, and why. International Journal of Qualitative Methods, 19, 1609406920938577.
Demers, M., Bishop, L., Cain, A., Saba, J., Rowe, J., Zondervan, D., & Winstein, C. (2023). Wearable technology to capture arm use of stroke survivors in home and community settings: feasibility and early insights on motor performance. medRxiv., 28. https://doi.org/https://dx.doi.org/10.1101/2023.01.25.23284790
Donnelly, M. R., Phanord, C. S., Marin-Pardo, O., Jeong, J., Bladon, B., Wong, K., Abdullah, A., & Liew, S. L. (2023). Acceptability of a Telerehabilitation Biofeedback System Among Stroke Survivors: A Qualitative Analysis. OTJR: Occupational Therapy Journal of Research, 43(3), 549-557. https://doi.org/https://dx.doi.org/10.1177/15394492231153998
Duddy, C., & Wong, G. (2023). Grand rounds in methodology: when are realist reviews useful, and what does a 'good' realist review look like? BMJ Qual Saf, 32(3), 173-180. https://doi.org/10.1136/bmjqs-2022-015236
Dumurgier, J., & Tzourio, C. (2020). Epidemiology of neurological diseases in older adults. Rev Neurol (Paris), 176(9), 642-648. https://doi.org/10.1016/j.neurol.2020.01.356
Durufle, A., Le Meur, C., Piette, P., Fraudet, B., Leblong, E., & Gallien, P. (2023). Cost effectiveness of a telerehabilitation intervention vs home based care for adults with severe neurologic disability: A randomized clinical trial. Digital Health, 9, 20552076231191001. https://doi.org/https://dx.doi.org/10.1177/20552076231191001
Epalte, K., Tomsone, S., Vētra, A., & Bērziņa, G. (2023). Patient experience using digital therapy "Vigo" for stroke patient recovery: a qualitative descriptive study. Disability & Rehabilitation: Assistive Technology, 18(2), 175-184. https://doi.org/10.1080/17483107.2020.1839794
Gaugler, J. E., Zmora, R., Peterson, C. M., Mitchell, L. L., Jutkowitz, E., & Duval, S. (2023). What interventions keep older people out of nursing homes? A systematic review and meta-analysis. J Am Geriatr Soc, 71(11), 3609-3621. https://doi.org/10.1111/jgs.18522
GBD 2021 Nervous System Disorders Collaborators. (2024). Global, regional, and national burden of disorders affecting the nervous system, 1990-2021: a systematic analysis for the Global Burden of Disease Study 2021. Lancet Neurol, 23(4), 344-381. https://doi.org/10.1016/s1474-4422(24)00038-3
Giraldo, L. F. G., Valencia-Arias, A., Suárez-Pizzarello, M., Flores, E. A. R., Rodríguez-Correa, P. A., Cardona-Acevedo, S., & Ohcoa, J. A. V. (2025). Integration of Technologies in Daily Life in Smart Homes: A Bibliometric Approach. Journal of Posthumanism, 5(5), 3206-3215. https://doi.org/https://doi.org/10.63332/joph.v5i5.1715
Goh, L., Allen, N. E., Ahmadpour, N., Martens, K. A. E., Song, J., Clemson, L., Lewis, S. J. G., MacDougall, H. G., & Canning, C. G. (2021). A Video Self-Modeling Intervention Using Virtual Reality Plus Physical Practice for Freezing of Gait in Parkinson Disease: Feasibility and Acceptability Study. JMIR Formative Research, 5(11). https://doi.org/10.2196/28315
Gooch, H. J., Jarvis, K. A., & Stockley, R. C. (2024). Behavior Change Approaches in Digital Technology-Based Physical Rehabilitation Interventions Following Stroke: Scoping Review. J Med Internet Res, 26, e48725. https://doi.org/10.2196/48725
Greenhalgh, T., & Abimbola, S. (2019). The NASSS Framework - A Synthesis of Multiple Theories of Technology Implementation. Stud Health Technol Inform, 263, 193-204. https://doi.org/10.3233/shti190123
ISO. (2018). Ergonomics of human-system interaction—Part 11: Usability: Definitions and concepts (ISO 9241-11: 2018). In.
Kamm, C. P., Blattler, R., Kueng, R., & Vanbellingen, T. (2023). Feasibility and usability of a new home-based immersive virtual reality headset-based dexterity training in multiple sclerosis. Multiple Sclerosis and Related Disorders, 71(no pagination). https://doi.org/https://dx.doi.org/10.1016/j.msard.2023.104525
Khan, F., Amatya, B., Galea, M. P., Gonzenbach, R., & Kesselring, J. (2017). Neurorehabilitation: applied neuroplasticity. J Neurol, 264(3), 603-615. https://doi.org/10.1007/s00415-016-8307-9
Kidritsch, A., Arntz, A., Freisleben-Teutscher, C., Grüneberg, C., Handgraaf, M., Heller, M., Jakl, A., Jokinen, K., Korniloff, K., Riquelme, I., Velasco-

Roldán, O., Weber, F., & Lällä, K. (2023). DIRENE: International collaborative definition of terminologies: A consensus process of five European higher education institutions on terms that are relevant for teaching digital rehabilitation competences via mobile devices. In J. Weißenböck (Ed.), Lernen über den Tellerrand hinaus – Good Practices zu Interdisziplinarität, Internationalisierung und Future Skills (pp. 79–96). Lemberger Publishing. https://tagderlehre.fhstp.ac.at/content/download/211637/file/TdL_Tagungsband2023.pdf

Kim, H., & Kim, G. J. (2022). Attitudes and use patterns for mobile technology and upper extremity home exercises in stroke survivors in the United States. British Journal of Occupational Therapy, 85(9), 677-684. https://doi.org/10.1177/03080226211070564

Königs, M., Beurskens, E. A., Snoep, L., Scherder, E. J., & Oosterlaan, J. (2018). Effects of Timing and Intensity of Neurorehabilitation on Functional Outcome After Traumatic Brain Injury: A Systematic Review and Meta-Analysis. Arch Phys Med Rehabil, 99(6), 1149-1159.e1141. https://doi.org/10.1016/j.apmr.2018.01.013

Lambercy, O., Lehner, R., Chua, K., Wee, S. K., Rajeswaran, D. K., Kuah, C. W. K., Ang, W. T., Liang, P., Campolo, D., Hussain, A., Aguirre-Ollinger, G., Guan, C., Kanzler, C. M., Wenderoth, N., & Gassert, R. (2021). Neurorehabilitation From a Distance: Can Intelligent Technology Support Decentralized Access to Quality Therapy? Front Robot AI, 8, 612415. https://doi.org/10.3389/frobt.2021.612415

Lau, F., & Kuziemsky, C. (2016). Handbook of eHealth evaluation: an evidence-based approach.

Lawson, T. (1997). Economics and reality. Routledge.

Lee, J. I., Park, J., Koo, J., Son, M., Hwang, J. H., Lee, J. Y., & Chang, W. H. (2023). Effects of the home-based exercise program with an augmented reality system on balance in patients with stroke: a randomized controlled trial. Disability & Rehabilitation, 45(10), 1705-1712. https://doi.org/10.1080/09638288.2022.2074154

Levy, T., Killington, M., Lannin, N., & Crotty, M. (2021). Viability of using a computer tablet to monitor an upper limb home exercise program in stroke. https://search.ebscohost.com/login.aspx?direct=true&db=ccm&AN=148301460&lang=fr&site=ehost-live

Maddahi, A., Hani, J. B., Asgari, A., Nassiri, A. M., & Choukou, M. A. (2021). Therapists' perspectives on a new portable hand telerehabilitation platform for home-based personalized treatment of stroke patients. European Review for Medical and Pharmacological Sciences, 25(18), 5790-5800. https://doi.org/10.26355/eurrev_202109_26797

Marin-Pardo, O., Donnelly, M. R., Phanord, C. S., Wong, K. R., Pan, J. S. C., & Liew, S. L. (2022). Functional and neuromuscular changes induced <i>via</i> a low-cost, muscle-computer interface for telerehabilitation: A feasibility study in chronic stroke. Frontiers in Neuroergonomics, 3. https://doi.org/10.3389/fnrgo.2022.1046695

Martinez-Martin, E., & Cazorla, M. (2019). Rehabilitation Technology: Assistance from Hospital to Home. Comput Intell Neurosci, 2019, 1431509. https://doi.org/10.1155/2019/1431509

McClure, J., & Leah, C. (2021). Is independence enough? Rehabilitation should include autonomy and social engagement to achieve quality of life. Clinical Rehabilitation, 35(1), 3-12. https://doi.org/10.1177/0269215520954344

McConnell, T., Blair, C., Reid, J., & Wong, G. (2025). The potential of programme theory in bridging the evidence into practice gap in implementation science: a worked example of integrating palliative care into heart failure management. BMC Health Services Research, 25(1), 622. https://doi.org/10.1186/s12913-025-12779-6

Nam, C., Zhang, B., Chow, T., Ye, F., Huang, Y., Guo, Z., Li, W., Rong, W., Hu, X., & Poon, W. (2021). Home-based self-help telerehabilitation of the upper limb assisted by an electromyography-driven wrist/hand exoneuromusculoskeleton after stroke. Journal of NeuroEngineering & Rehabilitation (JNER), 18(1), 1-18. https://doi.org/10.1186/s12984-021-00930-3

Nilsen, P. (2015). Making sense of implementation theories, models and frameworks. Implement Sci, 10, 53. https://doi.org/10.1186/s13012-015-0242-0

O'Neil, J., Egan, M., Marshall, S., Bilodeau, M., Pelletier, L., & Sveistrup, H. (2023). Remotely Supervised Exercise Programmes to Improve Balance, Mobility, and Activity Among People with Moderate to Severe Traumatic Brain Injury: Description and Feasibility. Physiotherapy Canada, 75(2), 146-155. https://doi.org/10.3138/ptc-2021-0039

Olsen, S., Lim, X. M. L., Alder, G., Stavric, V., & Signal, N. (2025). Factors influencing adoption and sustained use of rehabilitation technologies: a scoping review and qualitative analysis. Disabil Rehabil Assist Technol, 20(4), 804-822. https://doi.org/10.1080/17483107.2024.2435571

Osuagwu, B. A. C., Timms, S., Peachment, R., Dowie, S., Thrussell, H., Cross, S., Shirley, R., Segura-Fragoso, A., & Taylor, J. (2020). Home-based rehabilitation using a soft robotic hand glove device leads to improvement in hand function in people with chronic spinal cord injury:a pilot study. Journal of NeuroEngineering and Rehabilitation, 17(1) (no pagination). https://doi.org/https://dx.doi.org/10.1186/s12984-020-00660-y

Pawson, R. (2006). Evidence-based policy: a realist perspective. SAGE Publications.

Pawson, R., Greenhalgh, T., Harvey, G., & Walshe, K. (2005). Realist review--a new method of systematic review designed for complex policy interventions. J Health Serv Res Policy, 10 Suppl 1, 21-34. https://doi.org/10.1258/1355819054308530

Pawson, R., & Tilley, N. (1997). Realistic evaluation. sage.

Peters, L. A. (2024). An exploration of analytical tools to conduct a realist synthesis and demonstrate programme theory development: An example from a realist review. Research Methods in Medicine & Health Sciences, 26320843231224807.

Power, J., Dada, S., Booth, A., De Brún, A., & Gilmore,

B. (2024). Advisory groups in realist reviews: Systematically mapping current research and recommendations for practice. Cochrane Evidence Synthesis and Methods, 2(6), e12073.

Rogers, E. M. (2003). Diffusion of innovations (5th edition ed.). New York: Free Press.

Rozevink, S. G., van der Sluis, C. K., Garzo, A., Keller, T., & Hijmans, J. M. (2021). HoMEcare aRm rehabiLItatioN (MERLIN): telerehabilitation using an unactuated device based on serious games improves the upper limb function in chronic stroke. Journal of NeuroEngineering and Rehabilitation, 18(1) (no pagination). https://doi.org/https://dx.doi.org/10.1186/s12984-021-00841-3

Shearn, K., Allmark, P., Piercy, H., & Hirst, J. (2017). Building Realist Program Theory for Large Complex and Messy Interventions. International Journal of Qualitative Methods, 16(1), 1609406917741796. https://doi.org/10.1177/1609406917741796

Standen, P., Threapleton, K., Connell, L., Richardson, A., Brown, D. J., Battersby, S., Sutton, C. J., & Platts, F. (2015). Patients' Use of a Home-Based Virtual Reality System to Provide Rehabilitation of the Upper Limb Following Stroke. Physical Therapy, 95(3), 350-359. https://doi.org/10.2522/ptj.20130564

Taylor-Piliae, R. E., Mohler, M. J., Najafi, B., & Coull, B. M. (2016). Objective fall risk detection in stroke survivors using wearable sensor technology: a feasibility study. Topics in Stroke Rehabilitation, 23(6), 393-399. https://doi.org/https://dx.doi.org/10.1179/1074935715Z.00000000059

Tyagi, S., Lim, D. S. Y., Ho, W. H. H., Koh, Y. Q., Cai, V., Koh, G. C. H., & Legido-Quigley, H. (2018). Acceptance of Tele-Rehabilitation by Stroke Patients: Perceived Barriers and Facilitators. Archives of Physical Medicine and Rehabilitation, 99(12), 2472-2477. https://doi.org/10.1016/j.apmr.2018.04.033

Valdes, B. A., Glegg, S. M. N., Lambert-Shirzad, N., Schneider, A. N., Marr, J., Bernard, R., Lohse, K., Hoens, A. M., & Van der Loos, H. F. M. (2018). Application of Commercial Games for Home-Based Rehabilitation for People with Hemiparesis: Challenges and Lessons Learned. Games for health journal, 7(3), 197-207. https://doi.org/https://dx.doi.org/10.1089/g4h.2017.0137

van den Bergh, R., Evers, L. J. W., de Vries, N. M., Silva de Lima, A. L., Bloem, B. R., Valenti, G., & Meinders, M. J. (2023). Usability and utility of a remote monitoring system to support physiotherapy for people with Parkinson's disease. Frontiers in Neurology, 14(no pagination). https://doi.org/https://dx.doi.org/10.3389/fneur.2023.1251395

Venkatesh, V., & Bala, H. (2008). Technology acceptance model 3 and a research agenda on interventions. Decision sciences, 39(2), 273-315.

Wang, Y., Wong, E. L.-Y., Nilsen, P., Chung, V. C.-h., Tian, Y., & Yeoh, E.-K. (2023). A scoping review of implementation science theories, models, and frameworks — an appraisal of purpose, characteristics, usability, applicability, and testability. Implementation Science, 18(1), 43. https://doi.org/10.1186/s13012-023-01296-x

Westerlund, A., Sundberg, L., & Nilsen, P. (2019). Implementation of Implementation Science Knowledge: The Research-Practice Gap Paradox. Worldviews Evid Based Nurs, 16(5), 332-334. https://doi.org/10.1111/wvn.12403

Wittmann, F., Held, J. P., Lambercy, O., Starkey, M. L., Curt, A., Hover, R., Gassert, R., Luft, A. R., & Gonzenbach, R. R. (2016). Self-directed arm therapy at home after stroke with a sensor-based virtual reality training system. Journal of Neuroengineering & Rehabilitation, 13(1), 75. https://doi.org/https://dx.doi.org/10.1186/s12984-016-0182-1

Wong, G. (2018). Data gathering in realist reviews: looking for needles in haystacks. Doing realist research. London: SAGE, 131-145.

Wong, G., Greenhalgh, T., Westhorp, G., Buckingham, J., & Pawson, R. (2013). RAMESES publication standards: realist syntheses. BMC Med, 11, 21. https://doi.org/10.1186/1741-7015-11-21

World Health, O. (2018). Classification of digital health interventions V1. 0: a shared language to describe the uses of digital technology for health. https://iris.who.int/bitstream/handle/10665/260480/WHO-RHR-18.06-eng.pdf?sequence=1

World Health Organization. (2019). WHO guideline Recommendations on Digital Interventions for Health System Strengthening. In. World Health Organization.

Zhang, L., Yan, Y. N., Sun, Z. X., Yan, D. R., Chen, Y. W., Lin, K. C., Ge, X. J., & Qin, X. L. (2022). Effects of Coaching-Based Teleoccupational Guidance for Home-Based Stroke Survivors and Their Family Caregivers: A Pilot Randomised Controlled Trial. International Journal of Environmental Research and Public Health, 19(23) (no pagination). https://doi.org/https://dx.doi.org/10.3390/ijerph192316355

Veronese, N., Custodero, C., Demurtas, J., Smith, L., Barbagallo, M., Maggi, S., Cella, A., Vanacore, N., Aprile, P. L., & Ferrucci, L. (2022). Comprehensive geriatric assessment in older people: An umbrella review of health outcomes. Age and Ageing, 51(5), afac104.

Vuong, N., Chan, S., Lau, C., & Lau, K. (2011). A predictive location-aware algorithm for dementia care. 339–342.

Wang, R., Aung, M. S., Abdullah, S., Brian, R., Campbell, A. T., Choudhury, T., Hauser, M., Kane, J., Merrill, M., & Scherer, E. A. (2016). CrossCheck: Toward passive sensing and detection of mental health changes in people with schizophrenia. 886–897.

Wang, R., Wang, W., DaSilva, A., Huckins, J. F., Kelley, W. M., Heatherton, T. F., & Campbell, A. T. (2018). Tracking depression dynamics in college students using mobile phone and wearable sensing. Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies, 2(1), 1–26.

Wannenburg, J., & Malekian, R. (2015). Body sensor network for mobile health monitoring, a diagnosis

and anticipating system. IEEE Sensors Journal, 15(12), 6839–6852.
Wannenburg, J., Malekian, R., & Hancke, G. P. (2018). Wireless capacitive-based ECG sensing for feature extraction and mobile health monitoring. IEEE Sensors Journal, 18(14), 6023–6032.
Wild, K., Boise, L., Lundell, J., & Foucek, A. (2008). Unobtrusive in-home monitoring of cognitive and physical health: Reactions and perceptions of older adults. Journal of Applied Gerontology, 27(2), 181–200.
Wu, C.-Y., Dodge, H. H., Gothard, S., Mattek, N., Wright, K., Barnes, L. L., Silbert, L. C., Lim, M. M., Kaye, J. A., & Beattie, Z. (2022). Unobtrusive sensing technology detects ecologically valid spatiotemporal patterns of daily routines distinctive to persons with mild cognitive impairment. The Journals of Gerontology: Series A, 77(10), 2077–2084.
Wu, C.-Y., Dodge, H. H., Reynolds, C., Barnes, L. L., Silbert, L. C., Lim, M. M., Mattek, N., Gothard, S., Kaye, J. A., & Beattie, Z. (2021). In-home mobility frequency and stability in older adults living alone with or without MCI: introduction of new metrics. Frontiers in Digital Health, 3, 764510.
Wu, X., Freeman, S., Miyagi, M., Park, U., Nomura, K., & Ebihara, S. (2024). Comprehensive Geriatric Assessment in the era of telemedicine. Geriatrics & Gerontology International, 24, 67–73.
Xu, H., & Plataniotis, K. N. (2016). EEG-based affect states classification using deep belief networks. 148–153.
Yamada, Y., Kisvetrová, H., & Topinková, E. (2014). Evaluation of a pilot study to introduce outcome based home care in the Czech Republic. Kontakt, 16(3), e149–e154.
Yamada, Y., Shinkawa, K., & Shimmei, K. (2020). Atypical repetition in daily conversation on different days for detecting alzheimer disease: Evaluation of phone-call data from a regular monitoring service. JMIR Mental Health, 7(1), e16790.
Yu, L., Chan, W. M., Zhao, Y., & Tsui, K.-L. (2018). Personalized health monitoring system of elderly wellness at the community level in Hong Kong. IEEE Access, 6, 35558–35567.
Zhang, J., & Wu, Y. (2018). Automatic sleep stage classification of single-channel EEG by using complex-valued convolutional neural network. Biomedical Engineering/Biomedizinische Technik, 63(2), 177–190.
Zhou, X. (2020). Wearable health monitoring system based on human motion state recognition. Computer Communications, 150, 62–71.