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# The Technology Used in Assessment or Training of Task-Specific Strength in the Upper Extremity: A Scoping Review

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## Abstract

**Background:** Advances in technology allow the use of different systems in the training of motor performance. The aim of this review is to provide an overview of currently available technical interactive systems for the assessment and training of the upper extremity in humans, and challenges in their use, in relation to activities of daily life (ADL).

**Method:** A scoping review was conducted, using the search engines PubMed, Web of Science and Embase.

**Results:** In total, 160 papers were selected. Three main categories of technology were identified: camera-based, sensor-based, and combination systems. Sensor-based technology was most frequently used, with Inertial Measurement Units and accelerometer sensors. Combination systems included different technologies, such as Virtual Reality, Augmented Reality, game rehabilitation systems, internet-based systems, and 3D electromagnetic systems. Outcome, aim of each technology, different target populations, and placement on the upper extremity (UE) are summarized for those three categories.

**Conclusion:** This scoping review evaluates various technologies for assessing and training UE motor performance in ADL in individuals with impairments. The review identifies a lack of a single comprehensive tool to effectively measure and improve multiple outcomes, including task-specific strength in the UE and object positioning during ADL or movement. Our findings suggest the need to develop technologies that can serve as comprehensive tools for the assessment and training of UE motor performance in individuals with impairments.

***Keyword:*** *Technology; Upper Extremity; Activity of Daily Life; Rehabilitation*

## Introduction

Motor performance is the ability to perform a motor task and covers a variety of terms (e.g. motor skills, motor abilities) used to describe goal-directed human movement [1]. Motor performance is always observable and is influenced by many factors such as motivation, attentional focus, fatigue, and physical condition [2]. Impairments in motor performance can significantly impact daily activities and overall independence, particularly in individuals with motor and cognitive disorders. For example, children with cerebral palsy (CP), stroke, or muscle diseases often experience difficulties in upper extremity (UE) motor performance, due to muscle weakness, spasticity, or reduced selectivity, which can lead to challenges in tasks like dressing, lifting, and carrying objects [3-5]. Addressing these deficits in rehabilitation is crucial to enhancing the child's mobility, activity level, and overall participation [6,7].

In evaluating UE motor performance, it is essential to consider factors such as muscle strength, timing, speed, accuracy in positioning objects, and the execution of daily tasks [2]. To drink from a coffee mug, one needs sufficient hand muscle strength to lift and position precisely the mug to allow one to drink the coffee without spilling. The level of muscle strength of the upper limb and accuracy of movement and positioning of the object play important roles in the execution of a high-quality and successful movement. While current assessments like the maximal voluntary contraction (MVC) using handheld dynamometers are valuable for measuring strength, they do not capture functional aspects during task performance [8,9]. Other existing tools like the Box Task, Cup Task, and Task-oriented Arm-hAnd Capacity (TAAC) instrument assess MVC during daily tasks, but a comprehensive tool evaluating strength and accuracy simultaneously during task performance is lacking [10].

Technological advancements have opened new possibilities for assessing and enhancing motor performance in individuals with movement disabilities as well as healthy subjects (e.g. athletes). Robotics, orthotics, wearable sensors, computer vision, computer gaming, electrical stimulation, virtual reality, machine learning, and computational modeling have emerged as promising technologies in this domain [11]. These technologies offer opportunities for testing and training, providing interactive feedback to improve motor performance tailored to the specific needs of individuals.

So, the aim of our study is to investigate technology or interactive systems used for assessing and training motor performance of daily activities (ADL) with objective characteristics related to UE motor performance, such as muscle strength, motor fatigability [12] and object positioning while performing a specific task in all kinds of populations. Even though the main interest is in children with CP, we specifically did not restrict our search to this population as new development in other populations including healthy populations, could be very valuable. Up until now, one systematic review has shown that wearable systems predominantly find application in monitoring and providing feedback on posture and upper extremity movements during stroke rehabilitation [13]. Another review provided an overview of sensor-technology used during upper limb tasks in multiple populations with movement disorders [14]. We did not find a review paper that described all kinds of different technical interactive systems used in UE motor performance testing and assessment.

This scoping review aims to provide an overview of currently available technical interactive systems for the assessment and training of the UE in humans of motor performance of ADL activities, with a discussion of their challenges as well as opportunities and ideas for their combination and/or development of new technologies. Furthermore, we aim to classify these systems with reference to muscle strength, object positioning, and movement accuracy in the UE.

## Methods

The method of this scoping review follows PRISMA guidelines. The protocol was preregistered with the Open Science Framework (OSF) (Registration DOI https://doi.org/10.17605/OSF.IO/UE9ZC).

### Eligibility criteria

Studies were selected according to the following criteria:

- Inclusion criteria:

  1. Studies related to healthy persons or persons with all kinds of pathology, and of any age.
  2. Studies must be related to the assessment or training of the UE (shoulder, elbow, wrist, hand, and fingers) focusing on tasks or activities of daily living.

3. A technological device or interactive system is used for assessment or training.
4. Published in English.
5. At least one of the following outcomes must be assessed (diagnostic, evaluation) for feedback using a technical device:
    - Static strength (Peak, Maximal Voluntary Contraction, fatigability),
    - Dynamic strength (power, force, velocity, acceleration),
    - Motor performance/movement accuracy (trajectory length/path),
    - Position (object or person) accuracy,
    - Position angle or eigenvector.

- Exclusion criteria:

1. Studies with treatments involving drugs or alcohol.
2. Studies using invasive technologies, such as needles placed on the body for purposes of EMG or electrical stimulation.
3. Technology that takes over or supports the movement or force generation of the person, such as robotic exoskeletons or orthotics.
4. Conference abstracts.

## Search strategy

A search strategy was developed by two reviewers (HG, IH) using medical subject headings (MeSH terms) and text words in the title and abstract related to the research questions. The strategy was prepared in collaboration with a librarian. Only articles published up until 28th August 2023, on which the date the search was conducted) were included. Meta-analyses and systematic reviews (these will only be used to identify original studies not found through normal searches).

Topics in the search are technology, upper extremity, outcome measures for strength and accuracy in dynamic performance (movement) and static performance (position), rehabilitation, and ADL. First, the search strategy for PubMed was established, which includes all usable MeSH and text words to search in titles and abstracts according to the topics.

Then the strategy was adapted to the syntax and subject headings of the other databases. The search strategy is included in appendix A.

## Selection process

A systematic search was conducted in the PubMed, Web of Science, and Embase databases up to 28th August 2023. Following deduplication, title and abstract screening were conducted independently by two reviewers (HG, IH) based on the pre-determined selection criteria. Full-text screening was conducted independently by the same two reviewers (HG, IH), with reasons for exclusion documented and conflicts being resolved through discussion. If there was a disagreement between two reviews, a third reviewer (ER) made the final decision.

## Data extraction process

Data extraction was done by one reviewer (HG), using a standard form. The following data were extracted (See tables): 1) Study population; 2) Details of technologies used; 3) Which part of the UE is measured or trained; 4) Reported outcome measures for strength and/or object position; 5) The aim of each technology (such as assessment for diagnostics and/or evaluation of treatment effect and training/rehabilitation). The decision about the classification of the technologies will be based on the findings of the scoping review.

## Results

### Database search and article lists

The PRISMA flowchart (Figure 1) describes the screening process. Searches identified 3118 studies (PubMed: n = 1591; Web of Science: n = 785; Embase: n = 742): after the full selection process, we included 160 studies in this review. The original characteristics of the different technology types, target population, placement on the body, the outcomes of the technology, and the aim of the technology utilization are summarized in appendix B.

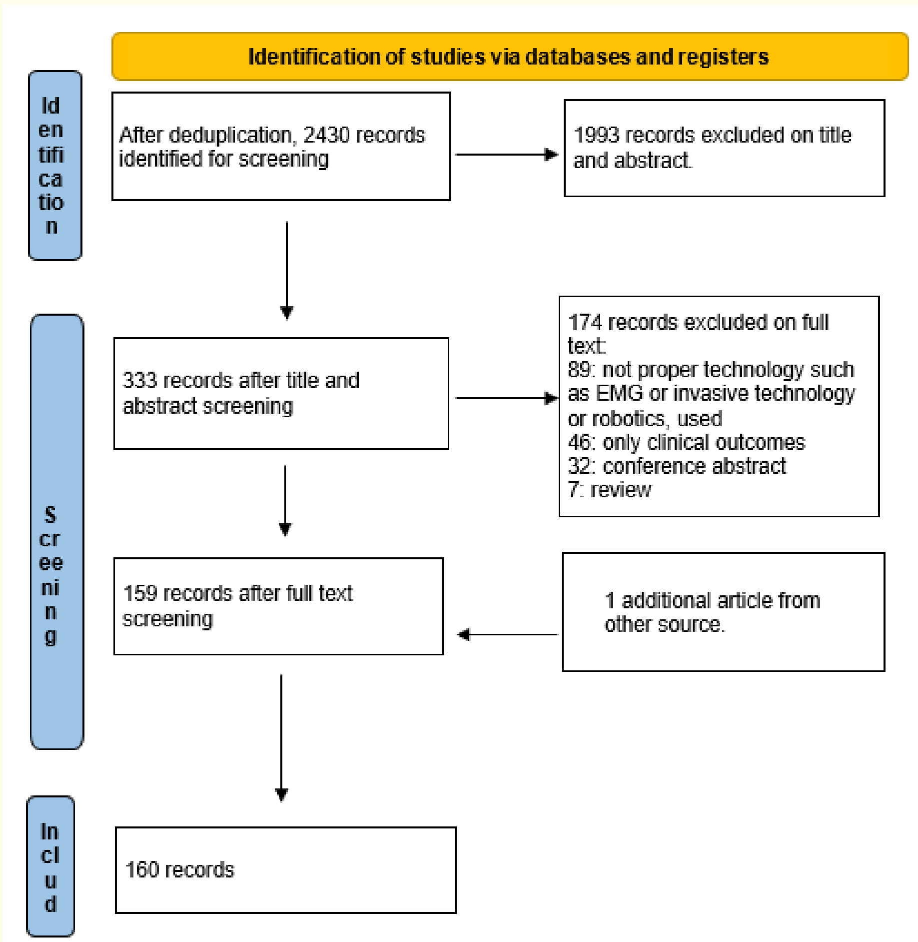


***Figure 1:*** *PRISMA study flow diagram.*

### Results for types of technology

Based on the results the technologies are classified into three main categories (See table 1).

1. Camera-based: Technology using at least one camera, including some or all of the following components: 3D motion analyzer, video camera, optoelectronic tracking system, egocentric camera, and motion capture system.
2. Sensor-based: Technologies comprising sensors, such as electromagnetic tracking devices, inertial measurement units (IMU), wearable sensors, force sensors and accelerometer sensors.
3. Combination systems: These combine different technologies, such as virtual reality (VR) systems, augmented reality (AR) systems, game rehabilitation systems, internet-based systems, a 3D electromagnetic system, hand function assessment system, hand motion tracking system, etc.

Camera-based technologies were widely used in evaluating ADL involving the human body and its interaction with objects. Thirty studies involved these technologies (1-30). The number of cameras varied from one head-mounted egocentric camera to a sixteen-camera-based motion capture system. Motion analysis (with optical three-dimensional (3D) motion analyzers) has more applications in other fields, such as gait analysis and computer graphics. This type of technology appears applicable to the quantitative analysis of UE motions. The UE trajectory on the human body is detected by the camera, and joint angle, movement smoothness, velocity, and force are calculated by a computer algorithm. In three studies (11-13), a head-mounted egocentric camera was used in a simulated home situation to record how participants performed various ADL activities in different room settings. These included tasks such as food preparation in the living room and beverage preparation at the kitchen counter. In 27 papers (1-10, 14-30), motion capture systems were used in recording the movement of the object or upper limbs.

The sensor-based technology is the most used (90 out of 160) of which IMU sensor (31-66, 70-79, 82-87, 89-90, 152,154-156,159) and accelerometer sensor (93-115) are the most frequently used. An IMU is an electronic device that measures a body's specific force, angular rate, and sometimes the orientation of the body, using a combination of accelerometers, gyroscopes, and sometimes magnetometers. Accelerometer or IMU-based systems typically consist of several sensor nodes and can measure kinematic parameters such as orientation, position, and velocity, as well as complex body posture and joint range of motion. Eleven articles (67-69, 74, 79-81, 88, 91-92) used specific force sensors to evaluate muscle strength.

The combination systems included different technologies together. Thirteen articles (116,118,120,122,125-126,139,144-146,148-149,153,157,160) used VR or AR technologies that were combined with a gaming platform that was used for training or rehabilitation. One article (149) used the VR system to improve upper-limb function in children with CP [15]. Two rehabilitation systems (119,141) focused on hand and arm with ADL-related games. One Internet-based system (121) designed for people with a stroke was used at home. A 3D-electromagnetic system (123) was used for the assessment of upper limb function. And a few studies used a more functional assessment system such as Instrumented Measure–Spoon (AIM-S) system (128), a book-shaped system, or instrumented pen and forks (135), which are more related to ADL. One platform (140) consists of a smart cup embedded with sensors to monitor object position.

| | | |
|---|---|---|
| Camera-based technology | Motion capture system | 1-10,14-30 |
| | Egocentric camera | 11-13 |
| Sensor-based technology | IMU/Inertial sensor | 31-66,70-79,82-87,89-90,152,154-156,159 |
| | Accelerometer | 93-115 |
| | Force measurement sensor | 67-69, 74, 79-81,88, 91-92 |
| Combination systems | VR or AR | 116,118,120,122,125-126,139,144-146,148-149,153,157,160 |
| | Gaming Platform | 119,141 |
| | Others | 117,121,123-124,127-138,140,142-143,147,150-151,158 |

***Table 1:*** *Classification of different technologies.*

*Abbreviations: IMU: Inertial Measurement Unit; VR: Virtual Reality; AR: Augmented Reality.*

### Results for outcomes measures

The classifications are presented in appendix C. Each classification type comprises two domains: type of technology and outcome measures used. These are grouped into four areas.

First, movements of the upper limb (studies 1-11,14-29,31-36,39,41-43,45,48,52-53,55-56,60-61,70-71,73,75-78,82-87,89-90,92,96,110,116-117,118-129,131,136-139,142-149,152,154-155,157) or of an object (11-13, 74,150), including range of motion, velocity, motion trajectory, etc. Range of motion measurement is discussed in 53 articles. Measurement of velocity and acceleration is the subject of 15 articles. Fourteen articles assess movement smoothness or movement trajectory. Second, the outcome of force or muscle strength, including peak force and motor fatigability, is addressed in 27 studies (3,30,40,44,46,64,66-69,74,79-81,88,91-92,117,130,132-133,135,141,143,145,150-151). Third, 36 articles (37-38, 47, 49-51, 54, 57-59, 62-63, 65, 72, 93-95, 97-109,111-115,134,153,156,159-160) are related to the daily activity outcome. Fourth, the position of an object during a specific task or activity is described in five articles (11-13,74,150). In summary, the studies covered a diverse range of topics, including UE movements, force or muscle strength, daily activity outcomes, and object positioning during tasks. These results highlight the many approaches using technology to enhance motor performance across different domains.

We found only two papers (74,150) describing a technique that could be used to assess task-specific strength and object location during ADL. Bobin., *et al*. (74) offered a novel platform for monitoring the arm and hand activity of stroke patients. The platform features a smart cup that may be used to simulate everyday behaviors such as drinking. The intelligent cup is fitted with a variety of sensors that capture data on vibrations, orientation, liquid level, and location relative to a reference target. The sipping task also measures grip strength. Additionally, the prototype has auditory and visual displays that provide feedback to users on their movements [16].

The other study (150) presented the design and development of a unique platform for monitoring the force and torque of the entire human body. Based on multichannel force/torque measurements on the entire body collected during ADL under isometric settings, a platform comprising many devices is used to evaluate post-stroke patients. Some item positions, such as that of a wheelchair, can be monitored throughout daily activities [17].

### Results for the use of technology for assessment or rehabilitation

The classification of aims for each technology is presented in appendix D. In figure 2 it shows the aims and outcomes (assessment or evaluation) for different technologies. One key finding is that a large majority of technologies are being used for assessment (diagnostic, as well as treatment evaluation), with only a small proportion being used for training or rehabilitation. This suggests that more research could be applied to converting these technologies towards training in motor performance. The majority of the camera-based and sensor-based systems are used to assess UE movement; combination systems have a wider range of uses in both aims and outcomes.

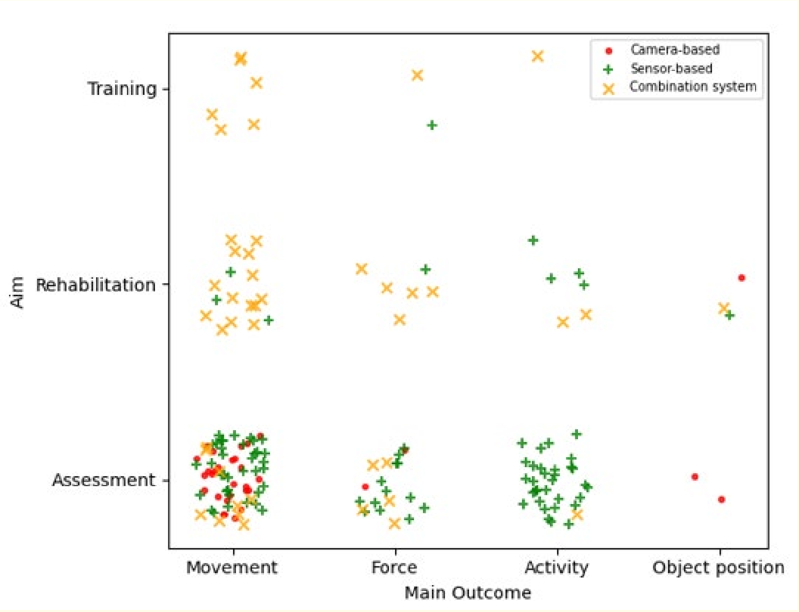


***Figure 2:*** *Aims and outcomes for different technologies.*

For assessment, we distinguish between diagnostic assessment for patients and evaluation effects for healthy subjects. Training refers to the process of developing and improving performance through exercises and practice. Rehabilitation refers to the process of helping recover from an injury or illness. In summary, training focuses on improving performance, while rehabilitation focuses on restoring function and treating injuries. A total of 130 studies used technology for assessment purposes, 59 for diagnostic purposes and 74 for evaluation of effects, while only 15 used technology for training, and 35 for rehabilitation purposes.

### Result for target populations

The use of technology with healthy participants is described in 60 studies, while 95 describe the use of technology with patients suffering from the following diseases: stroke (n = 56), spinal cord injury (n = 12), shoulder injury (n = 5), mild cognitive impairment (n = 4), hand osteoarthritis (n = 3), CP (n = 3), distal radius fractures (n = 2), Parkinson's disease (n = 2), Friedreich's ataxia (n = 2), and other diseases (n = 12) including Duchenne muscular dystrophy, intellectual disabilities or memory disorder.

### Results for placement of technologies on the upper limb

Overview of the placement of the technologies is presented in figure 3.

Fifty-four technologies are applied to the hand, 18 to the wrist, 23 to the finger, 17 to the shoulder, 4 to the elbow, 13 to the arm, and 60 to the UE overall. Technologies used with the different target populations and their placement on the UE. Healthy people and stroke patients are the most targeted populations for the use of different technologies. Sensor-based technology is mostly placed on the hand and wrist, while no technology focuses solely on the elbow. Overall, this figure provides detailed information about the target populations, and the UE placements being targeted by the technologies being used to assess UE motor performance in humans.

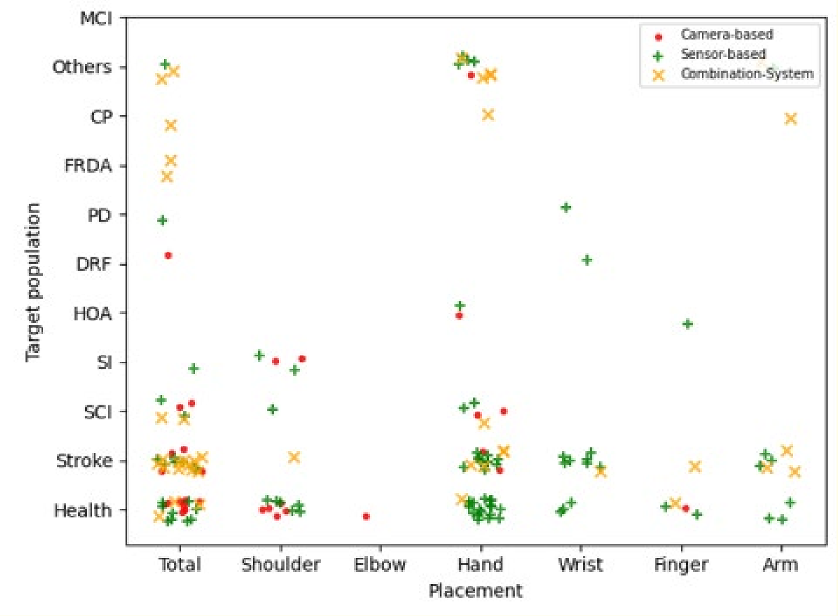


***Figure 3:*** *Technologies used and their placement, for different target populations.*

## Discussion

The purpose of this scoping review was to examine the current state of research and challenges for technologies and assessment tools used to enhance motor performance in the upper limb in many kinds of population. A second aim was to classify these systems with respect to muscle force, movement, daily activity, and object positioning with the UE.

The classification of technologies into camera-based, sensor-based, or combination systems provides a useful framework for understanding the various technologies currently used for the assessment and training of UE motor performance in humans. One key result is the wide range of measurement domains being used to assess upper limb motor performance, including movements of the upper limb, force or muscle strength, daily activity outcomes, and the position of objects during a specific tasks or activities. These domains provide valuable information about an individual's functional ability to perform ADL tasks and can be useful for tracking progress over time. A significant portion of the studies included in this review (approximately 37%) focus on healthy subjects, rather than on individuals with specific pathological conditions. Our research did not go into detail about the differences between technology used for children and adults or elderly people, or about the contrast between populations who are healthy and those that are impacted. Maybe further research should pay attention to that. In the field of children and children with cerebral palsy, the number of studies utilizing sensor technology to study accompanying motor performance is very small, representing approximately 5% of the population with all pathologies [14].

The technologies used for the upper limbs have a variety of purposes, including assessment, both diagnostic and evaluation, training, and rehabilitation. A previous study showed that wearable systems such as sensors like different sensors and accelerometers are primarily used to improve motor performance in UE rehabilitation [13]. The technologies we found are mainly used for assessment (n = 120), less frequently for training (n = 11) and rehabilitation (n = 33). We did not find any literature describing the preference for diagnosis-focused technology over training or rehabilitation focused technology at the moment. Maybe the reason is due to several factors, including the requirement for precise standards and progress tracking, regulatory concerns, clinical demands for diagnostic tools, and resource allocation. Wearable technology in healthcare faces adoption barriers due to dynamic interactions, developing training technologies frequently demands greater complexity and resources [18]. Even though testing may be the main focus right now, improvements in assessment could open the door to better training tools and a more all-encompassing strategy in the future.

### Types of technology

Most of the camera-based technologies are traditional optical or camera-based motion capture systems, typically laboratory-based and requiring markers to be attached to participants' skin. These markers act as reference points and are placed according to the underlying human anatomy, allowing segmental movement to be defined and joint angles to be calculated. They can provide detailed information about the movements of the upper limb, including range of motion, velocity, and acceleration. This can be particularly helpful in assessing motor function and identifying impairments in the UE. These systems are often considered the gold standard for motion capture due to their high accuracy and precision [19]. However, they have several limitations, including the need for specialized equipment and trained operators, the requirement for a controlled environment, and the need to attach markers to the skin, which can be uncomfortable for participants [20]. Lahkar., *et al*. found that the marker-less motion capture system may be a promising alternative for analyzing motor performance due to its practicality, as it can be used in the patient's own environment, although further research is needed to fully assess its accuracy and suitability for this purpose [21].

In the domain of sensor-based technology, such as electromagnetic sensors, mechanical sensors, optical sensors, and inertial sensors (e.g. accelerometers and IMUs), the latter are the most frequently utilized tools for analyzing upper limb motion, according to a recent review[13]. Sensor-based technology has the potential to increase adherence to home-based interventions by providing real-time sensory reminders to perform exercises and by providing objective feedback about the type and amount of UE exercises completed. This can be beneficial in both home-based and clinic rehabilitation settings [22]. Some accelerometers, IMUs, or sensor-embedded wearable devices such as sensorized gloves [23], wearable inertial rings, and bracelets [24] can track UE movement trajectories and record movement data. These sensors can also be customized for specific tasks or goals, which can help create personalized rehabilitation or training programs. Tramontano., *et al*. found that sensor-based training programs provide intensive and function-oriented rehabilitation that can be a good complementary strategy for hand rehabilitation in MS patients [25]. Many sensor-based technologies are portable, sourceless (meaning they do not require external references or markers), compact, and lightweight, making them suitable for portable motion-tracking applications [26]. One of the main challenges of using sensor-based technologies for rehabilitation in the home environment is the need to reduce the visibility or impact of the sensors and to ensure the accuracy of the exercises done at home [27].

The advantage of these kinds of combination systems is that some, combined with a variety of sensors or cameras, could be used to assess different outcomes at the same time and also be applied to the whole UE. One typical combination system specifically focuses on a platform designed to measure forces and torques being applied to the whole body. It could be useful for assessing the strength and stability of different body parts, as well as for developing targeted rehabilitation strategies. The challenge is also clear: some systems are huge and non-portable, requiring a large, open space, and it may not be practical or possible to set up the technology in some locations. VR systems are also widely used as combination systems, since VR has the potential to be a useful modality for motor rehabilitation after stroke [28]. It can provide an intensive and repetitive training environment that is essential for promoting neuroplasticity and improving motor recovery. VR can also be motivating for patients by increasing enjoyment and adding gamification elements, which can encourage participation and increase task repetition. The flexibility of VR allows for individualized rehabilitation designs, according to the patient's motor impairment, and can be used as an adjunctive therapy to conventional rehabilitation or as a telerehabilitation or home-based rehabilitation tool. VR systems can also be used to track patient progress and functional assessment using motion sensors [22].

### Outcomes and aims of technology utilization

Various outcomes have been measured in studies using technologies placed on the UE, including movements, force or muscle strength, daily activities, and object positioning during specific UE tasks or activities. Several studies have evaluated movements of the upper limb, using measures such as range of motion, velocity, acceleration, and movement smoothness or trajectory. Force or muscle strength has also been a common outcome studied. Koontz., *et al*. measured hand force with force sensors to investigate the effects of different hand and trunk positioning [29]. Measures such as peak force and motor fatigability are important outcomes in evaluating the strength and endurance of the UE muscles. Daily activity has been a focus of some studies, with accelerators the most frequent technology employed. Bochniewicz., *et al*. (50) present a method for measuring UE use in individuals with hemiparesis using a wrist-worn accelerometer. The method is inexpensive, objective, and accurate, and it has the potential to be used in restorative treatment trials to assess the impact of UE treatments [13].

A big gap in outcomes is that only a few studies focus on object positioning, and we were unable to identify any research on task-specific strength in combination with object positioning. Object positioning is important in movement accuracy in the upper limbs because it allows for efficient and effective use of the hand and arm during functional tasks. For example, if an object is positioned at the wrong angle or distance from the body, it can be difficult to grasp or manipulate the object, leading to decreased accuracy and increased effort. Task-specific strength training can be an effective way to improve functional ability and independence. Greater muscle strength, in the presence of proper object positioning, allows for even greater force generation and precision. Proper object positioning combined with stronger muscles, allows for more efficient and controlled movements, resulting in increased movement accuracy.

We only found two papers (74,150) relevant to UE strength and object position during ADL. Bobin., *et al*. describe a platform for monitoring the arm and hand activity of stroke patients during rehabilitation exercises in hospital and at home. This comprises a self-contained smart cup equipped with sensors that collect information about its orientation, liquid level, position, and tremors, as well as giving audio and visual feedback to patients. The smart cup was designed following interviews with therapists and was tested in a preliminary study involving nine stroke patients. The results of this showed the cup to be well accepted by the majority of patients, with almost no concerns about its design or usability. But no results were presented on object positioning and muscle strength in this study [16]. Mazzoleni., *et al*. described the design and development of an innovative platform for measuring whole-body force and torque on human subjects. The platform, comprising many different devices, is used to assess post-stroke patients, based on multichannel force/

torque measurements on the entire body recorded during ADL tasks in isometric conditions [17], but the measurement of muscle strength and object positioning is not task-specific in daily activity living. The current study aims to identify and create technology capable of accurately evaluating UE motor performance through the measurement of muscle strength, movement, and object positioning during specific tasks. This technology is intended to be a means of evaluating and enhancing UE motor skills. The development of this technology may be based on existing prototypes and systems and could be expanded to incorporate the integration of additional ADL. The ultimate goal of this technology is to achieve the dual purpose of serving as a tool for the assessment of motor performance and as a means of training and rehabilitation for specific UE tasks.

## Conclusion

In this scoping review, several technologies for the assessment and training of the UE about motor performance in ADL were evaluated and classified based on various factors, including their characteristics, outcomes, target population, and body placement. Even though there are various technologies out there, we still don't have a single tool that can effectively measure and improve multiple outcomes all at once. What we really need is a tool that can measure task-specific strength in the upper extremities, while also detecting object positioning during daily activities or object and/or UE position during object movement for diagnosis or treatment purposes. We hope others can use this knowledge to further develop technologies to measure UE motor performance, including muscle strength or movement and object positioning in task-specific activities. Further research is needed to address this gap and to develop technologies that can serve as comprehensive tools for assessment and training of the UE in individuals with impairments in this.

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## Authors Contribution

H. Guo and I. Heus share co-first authorship on this manuscript, indicating that they contributed equally to the research and writing process.

## Appendix

| | Search query | Number of articles (28th August 2023) |
|---|---|---|
| 1 | Upper Extremity[MeSH] OR upper extremit*[tiab] OR upper limb*[tiab] OR upperlimb*[tiab] OR arm[tiab] OR arms[tiab] OR upperarm*[tiab] OR shoulder*[tiab] OR underarm*[tiab] OR elbow*[tiab] OR forearm*[tiab] OR hand*[tiab] OR wrist*[tiab] OR finger*[tiab] | |
| 2 | Technology[Mesh:NoExp] OR Techn*[tiab] OR User-Computer Interface[MeSH] OR User-computer interface*[tiab] OR Virtual System*[tiab] OR Wearable Electronic Devices[MeSH] OR device*[tiab] OR interactive system*[tiab] OR sensor*[tiab] OR sensor system*[tiab] OR Inertial Measurement Unit[tiab] OR IMU[tiab] OR kinect[tiab] OR Computer Simulation[MeSH] OR computer simulat*[tiab] OR Virtual realit*[tiab] OR Augmented realit*[tiab] OR augmented virtualit*[tiab] OR mixed realit*[tiab] OR Haptic technology[MeSH] OR haptic*[tiab] OR Exergaming[MeSH] OR exergam*[tiab] OR Video Games[MeSH] OR video gam*[tiab] OR Accelerometry [MeSH] OR acceleromet*[tiab] OR actigraph*[tiab] OR gyroscop*[tiab] OR force plate*[tiab] OR pressure plate*[tiab] OR physiological embodiment*[tiab] OR motion analysis system*[tiab] | |

| | | |
|---|---|---|
| 3 | Muscle Strength [MeSH] OR strength [tiab] OR isometric contraction[tiab] OR isotonic contraction[tiab] OR Maximum Voluntary contraction OR Muscle Fatigue [MeSH] OR muscle fatig* [tiab] OR muscular fatig* [tiab] OR motor fatig*[tiab] OR force*[tiab] OR resist* [tiab] OR muscle power [tiab] OR muscular power[tiab]OR velocity [tiab] OR acceleration [MeSH] OR accelerat* [tiab] OR posture [MeSH] OR posture*[tiab] OR position*[tiab] OR Psychomotor Performance [MeSH] OR motor performance*[tiab] OR motor coordination[tiab] OR task performanc*[tiab] OR motor activit*[tiab] OR movement accurac*[tiab] OR movement smooth*[tiab] OR traject*[tiab] OR Motion[MeSH] OR motion*[tiab] OR movement[MeSH] OR Movement*[tiab] OR Range of motion, articular[MeSH] OR range of motion*[tiab] OR ROM[tiab] OR joint flexibil*[tiab] OR joint mobilit*[tiab] OR Eigen Vector [tiab] | |
| 4 | Rehabilitation[MeSH] OR rehab*[tiab] OR exercis*[tiab] OR training*[tiab] OR therap*[tiab] OR occupational therap*[tiab] OR ergotherap*[tiab] OR Physical Therapy Modalities[MeSH] OR Physical Therapy Specialty[MeSH] OR physical therap*[tiab] OR physiotherap*[tiab] OR program*[tiab] | |
| 5 | (Animals [MeSH] OR animal* [tiab]) NOT (Human [MeSH]) | |
| 6 | Robotics [MeSH] OR robot* [tiab] OR Exoskeleton Device [MeSH] OR exoskeleton* [tiab] | |
| 7 | 2 NOT 6 | |
| 8 | Activities of daily living [MeSH] OR ADL [tiab] OR daily liv* [tiab] | |
| 9 | Alcohol-Related Disorders [Mesh] OR Alcohol Related disorder*[tiab] OR Alcohol problem*[tiab] OR Alcoholism [tiab] OR alcohol addict*[tiab] OR Illicit Drugs[Mesh] OR drug* [tiab] | |
| 10 | 4 NOT 9 | |
| 11 | (1 AND 7 AND 3 AND 10 AND 8) NOT 5 | 1591 |

**Web of Science**

| | | **Number of articles (28th August 2023)** |
|---|---|---|
| 1 | TS=(upper extremit* OR upper limb* OR upperlimb* OR arm OR arms OR upperarm* OR shoulder* OR underarm* OR elbow* OR forearm* OR hand* OR wrist* OR finger*) | |
| 2 | TS=(Techn*OR User-computer interface*OR Virtual System* OR device* OR interactive system* OR sensor* OR sensor system* OR Inertial Measurement Unit OR IMU OR kinect OR computer simulat* OR Virtual realit* OR Augmented realit* OR augmented virtualit* OR mixed realit* OR haptic* OR exergam* OR video gam* OR acceleromet* OR actigraph* OR gyroscop* OR force plate* OR pressure plate* OR physiological embodiment* OR motion analysis system) | |
| 3 | TS=(strength OR isometric contraction OR isotonic contraction OR Maximum Voluntary contraction OR muscle fatig* OR muscular fatig* OR motor fatig* force* OR resist* OR muscle power OR muscular power OR velocity OR accelerat* OR posture* OR position* OR motor performance* OR motor coordination OR task performanc* OR motor activit* OR movement accurac* OR movement smooth*OR traject*OR trajectory length OR trajectory path*OR motion* OR Movement* OR range of motion* OR ROM OR joint flexibil* OR joint mobilit* OR Eigen Vector) | |

| | | |
|---|---|---|
| 4 | TS=(rehab* OR exercis* OR training* OR therap* OR occupational therap* OR ergotherapy* OR physical therap* OR physiotherap* OR program*) | |
| 5 | TS=(animal* NOT Human*) | |
| 6 | TS=(robot* OR exoskeleton*) | |
| 7 | 2 NOT 6 | |
| 8 | TS= (ADL OR daily liv*) | |
| 9 | TS= (Alcohol-Related Disorder* OR Alcohol problem* OR Alcoholism OR alcohol addict*OR drug*) | |
| 10 | 4 NOT 9 | |
| 11 | (1 AND 7 AND 3 AND 10 AND 8) NOT 5 | 785 |

**Embase**

| | Search query | Number of articles (28th August 2023) |
|---|---|---|
| 1 | ‘upper limb’/exp OR (‘upper extremit*’ OR ‘upper limb*’ OR upperlimb* OR arm OR arms OR upperarm* OR shoulder* OR underarm* OR elbow* OR forearm* OR hand* OR wrist* OR finger*):ti,ab,kw | |
| 2 | ‘technology’/exp OR ‘accelerometer’/exp OR ‘accelerometry’/exp OR ‘video game’/exp OR ‘computer simulation’/exp OR ‘computer interface’/exp OR ‘wearable computer’/exp OR ‘sensor’/exp OR ‘motion analysis system’/exp OR (Techn* OR ‘User-computer interface*’ OR ‘Virtual System*’ OR device* OR ‘interactive system*’ OR sensor* OR ‘sensor system*’ OR ‘Inertial Measurement Unit’ OR IMU OR kinect OR ‘computer simulat*’ OR ‘Virtual realit*’ OR ‘Augmented realit*’ OR ‘augmented virtualit*’ OR ‘mixed realit*’ OR haptic* OR exergam* OR ‘video gam*’ OR acceleromet* OR actigraph* OR gyroscop* OR ‘force plate*’ OR ‘pressure plate*’ OR ‘physiological embodiment*’ OR ‘motion analysis system’):ti,ab,kw | |
| 3 | ‘muscle strength’/exp OR ‘muscle isotonic contraction’/exp OR ‘muscle isometric contraction’/exp OR ‘muscle fatigue’/exp OR ‘force’/exp OR ‘velocity’/exp OR ‘kinematics’/exp OR ‘motor performance’/exp OR ‘motor coordination’/exp OR ‘task performance’/exp OR ‘motion’/exp OR ‘movement’/exp OR ‘joint mobility’/exp<br>(‘motor fatig*’ OR ‘strength’ OR ‘isometric contraction*’ OR ‘isotonic contraction*’ OR ‘Maximum Voluntary contraction’ OR ‘muscle fatig*’ OR ‘muscular fatig*’ OR force* OR resist* OR ‘muscle power’ OR ‘muscular power’ OR velocity OR accelerat* OR posture* OR position* OR ‘motor performance*’ OR ‘motor coordination’ OR ‘task performanc*’ OR ‘motor activit*’ OR ‘movement accurac*’ OR ‘movement smooth*’ OR traject* OR ‘trajectory length’ OR ‘trajectory path*’ OR motion* OR Movement* OR ‘range of motion*’ OR ROM OR ‘joint flexibil*’ OR ‘joint mobilit*’ OR ‘Eigen Vector’):ti,ab,kw | |
| 4 | ‘rehabilitation’/exp OR ‘exercise’/exp OR ‘training’/exp OR ‘physiotherapy’/exp OR<br>(rehab* OR exercis* OR training* OR therap* OR ‘occupational therap*’ OR ergotherapy* OR ‘physical therap*’ OR physiotherap* OR program*):ti,ab,kw | |

| | | |
|---|---|---|
| 5 | ('animal'/exp OR animal:ti,ab,kw) NOT ('human'/exp) | |
| 6 | 'robot'/exp OR 'robotics'/exp OR 'exoskeleton (rehabilitation)'/exp OR (robot* OR exoskelet*):ti,ab,kw | |
| 7 | 'alcoholism'/exp OR 'alcohol abuse'/exp OR 'alcohol rehabilitation'/exp OR 'alcoholics anonymous'/exp OR 'drug'/exp OR (alcoholism OR alcohol* OR 'alcohol abuse' OR 'alcohol rehabilitation' OR 'alcohol addict*' OR drug*):ti,ab,kw | |
| 8 | 'daily life activity'/exp OR ('activity of daily li*' OR 'daily li* activity'):ti,ab,kw | |
| 9 | 2 not 6 | |
| 10 | 4 not 7 | |
| 11 | 1 and 3 and 8 and 9 and 10 | |
| 12 | 11 not 5 | 742 |

| Number | Reference | Technology | Outcome | Purpose | Target population | Placement |
|---|---|---|---|---|---|---|
| 1 | (S., *et al*. 2006) | 3D Motion Analyzer | ROM | Assessment | Healthy | Total |
| 2 | (Lee., *et al*. 2007) | 3D Motion Analyzer | ROM | Assessment | Healthy | Shoulder Elbow |
| 3 | (IA and GR, 2004) | Video Camera | Force ROM Moment | Assessment | Healthy | Shoulder Elbow |
| 4 | (C and UP, 2000) | Optoelectronic Tracking System | Motion | Assessment | Healthy | Total |
| 5 | (FB., *et al*. 2015) | IMU and Motion Capture System | Movement | Assessment | Stroke | Total |
| 6 | (Mesquita., *et al*. 2020) | 3D Motion Capture System | Velocity ROM Smoothness | Assessment | Healthy | Total |
| 7 | (Rundquist and Ludewig, 2005) | 3D Analysis | ROM | Assessment | Frozen Shoulder or Adhesive Capsulitis | Shoulder |
| 8 | (Stansfield., *et al*. 2018) | 3D Motion Analysis | ROM | Assessment | Healthy | Elbow Wrist Finger |
| 9 | (M., *et al*. 2019) | Motion Capture System | Motion | Assessment | Healthy | Total |
| 10 | (Ranganathan., *et al*. 2017) | Wearable Sensor System and Motion Capture System | Acceleration Angular Velocity | Assessment | Healthy | Total |
| 11 | (J., *et al*. 2019) | System Based On A Wearable Camera | Object Motion | Assessment | SCI | Hand |
| 12 | (MF., *et al*. 2021) | Head-Mounted Egocentric Camera | Object Motion | Assessment | Stroke | Hand |
| 13 | (J and J, 2018) | Egocentric Camera | Hand Object Position | Rehab | SCI | Hand |
| 14 | (Alt Murphy., *et al*. 2018) | 3D Motion Capture | Velocity Smoothness | Assessment | Stroke | Hand |
| 15 | (Lee., *et al*. 2016) | Camera | Velocity ROM | Assessment | Healthy | Total |

| | | | | | | |
|---|---|---|---|---|---|---|
| 16 | (Thrane., *et al*. 2019) | Motion Capture System | Velocity ROM | Assessment | Stroke | Total |
| 17 | (Alt Murphy., *et al*. 2011) | 5-Camera Capture System | Movement Velocity Smoothness | Assessment | Stroke | Total |
| 18 | (FA 3rd., *et al*. 2016) | Infrared Position Detection System | ROM | Assessment | Healthy | Shoulder |
| 19 | (K., *et al*. 2018) | Mount 8 Motion Tracking Cameras | Movement Trajectory | Assessment | MCI Patients | Hand |
| 20 | (B., *et al*. 2010) | Camera System | ROM | Assessment | Healthy | Shoulder |
| 21 | (MW., *et al*. 2014) | 3D Motion Analysis System | ROM | Assessment | Total Shoulder Arthroplasty | Shoulder |
| 22 | (EL., *et al*. 2017) | Optoelectronic Cameras | Smoothness, Velocity ROM | Assessment | Stroke | Total |
| 23 | (BJ and DB, 2019) | Motion Capture Sensors | ROM | Assessment | Healthy | Shoulder |
| 24 | (Matthew., *et al*. 2020) | Depth Camera Systems | ROM | Assessment | Healthy | Total |
| 25 | (Holland., *et al*. 2020) | Video Cameras | ROM | Assessment | Hand OA | Hand |
| 26 | (HT., *et al*. 2011) | 3D Motion Analysis System | ROM | Assessment | Healthy | Finger |
| 27 | (Murgia., *et al*. 2010) | 8-Camera Motion Capture System | ROM Velocity Acceleration | Assessment | Distal Radius Fracture | Total |
| 28 | (K., *et al*. 2007) | Camera 3D Motion Analysis System | ROM | Assessment | Healthy | Total |
| 29 | (Kankipati., *et al*. 2015) | 16-Camera 3D Motion Capture System | Force ROM | Assessment | SCI | Total |
| 30 | (AM., *et al*. 2011) | 6 Cameras 3D Motion Capture System | Force ROM | Assessment | SCI | Total |
| 31 | (HE., *et al*. 2006) | Electromagnetic Tracking Device, The Flock Of Birds (Ascension Technology Inc., Burlington, Vermont, USA) | ROM | Assessment | Healthy | Shoulder |

| | | | | | | |
|---|---|---|---|---|---|---|
| 32 | (Gil-Agudo., *et al*. 2013) | Xsens System (Inertial Sensor Motion Capture System Using Proposed Kinematic Model) | ROM | Assessment | Healthy | Shoulder Elbow Wrist |
| 33 | (K., *et al*. 2018) | Leap Motion Sensor | ROM | Assessment | Healthy | Hand Wrist Fingers |
| 34 | (B., *et al*. 2008) | Inertial Sensor | Acceleration And Angular Velocity | Assessment | Healthy | Shoulder |
| 35 | (RM., *et al*. 2019) | IMU | ROM | Assessment | Healthy | Shoulder |
| 36 | (S., *et al*. 2020) | IMU | ROM Trajectory | Assessment | Healthy | Hand |
| 37 | (M., *et al*. 2016) | Wrist-Worn Motion Sensors | Activity | Assessment | Healthy | Hand |
| 38 | (FM and R, 2022) | Wrist-Worn Inertial Sensors | Activity Counts And Arm Movement | Assessment | Healthy | Hand |
| 39 | (Vega-Gonzalez and Granat, 2005) | Activity Sensor | Movement Displacement | Assessment | Stroke | Total |
| 40 | (A., *et al*. 2014) | Wearable Sensors | Force And Activities | Assessment | Stroke | Total |
| 41 | (C., *et al*. 2013) | Inertial Sensors | Arm Velocity And Frequency Of Arm Usage | Assessment | Shoulder Surgery | Total |
| 42 | (B., *et al*. 2020) | Wrist-Worn Inertial Sensor | Quality Of Movement | Assessment | Stroke | Total |
| 43 | (Oubre., *et al*. 2020) | Wearable Inertial Sensors | Movement? | Assessment | Stroke | Total |
| 44 | (M., *et al*. 2020) | Sensor System | Force | Assessment | Hand OA | Hand Finger |
| 45 | (Dogan., *et al*. 2019) | Inertial Sensors | ROM | Assessment | Healthy | Total |
| 46 | (J., *et al*. 2017) | Wearable Force Sensors | Grip Force | Assessment | Healthy | Hand |
| 47 | (Ignacio Serrano., *et al*. 2017) | IMUs | Activity | Assessment | PD | Total |
| 48 | (G., *et al*. 2021) | IMU | ROM | Assessment | Healthy | Wrist |
| 49 | (JPO., *et al*. 2018) | IMU | Activity | Rehab | Stroke | Total |
| 50 | (EM., *et al*. 2017) | Wrist-Worn Sensor | Activity | Assessment | Stroke | Hand |
| 51 | (JP., *et al*. 2022) | IMU | Activity | Assessment | Stroke | Hand |
| 52 | (B., *et al*. 2020) | IMU | ROM | Assessment | After Surgical Treatment for Distal Radius Fractures | Wrist |
| 53 | (SB., *et al*. 2009) | IMU | Acceleration | Assessment | Stroke | Hand |
| 54 | (M., *et al*. 2016) | IMU | Activity | Assessment | SCI | Hand |

| | | | | | | |
|---|---|---|---|---|---|---|
| 55 | (BM., *et al*. 2011) | Body-Fixed Sensors | Power, Angular Velocity Moment | Assessment | After Shoulder Surgery | Shoulder |
| 56 | (S., *et al*. 2019) | IMU | ROM | Assessment | SCI | Total |
| 57 | (Kersten and Fethke, 2019) | IMU | Activity | Assessment | Healthy | Hand |
| 58 | (D and I, 2019) | IMU | Activity | Assessment | Healthy | Forearm |
| 59 | (G., *et al*. 2021) | IMU | Activity | Assessment | Healthy | Hand Finger Wrist |
| 60 | (Biswas., *et al*. 2015) | Inertial Sensors | ROM | Assessment Rehab | Healthy | Arm |
| 61 | (B., *et al*. 2016) | IMU | ROM | Assessment | Healthy | Shoulder |
| 62 | (RJ., *et al*. 2015) | Multiple Sensor Devices | Activity | Assessment | Healthy | Total |
| 63 | (Mallat., *et al*. 2022) | IMU | Activity | Assessment | Healthy | Total |
| 64 | (A., *et al*. 2004) | Force-Sensor | Grip Force | Assessment | Healthy | Hand |
| 65 | (Dobkin and Martinez, 2018) | Wearable Sensors | Activity | Assessment | Healthy | Hand |
| 66 | (MC., *et al*. 2005) | Smart Device | Twisting Strength | Assessment | Healthy | Hand Wrist |
| 67 | (A and M, 2001) | Hand Grasp Instrument | Force | Assessment | Healthy | Hand |
| 68 | (T., *et al*. 2017) | Iwakka Device | Grasping Force | Assessment | Healthy | Hand |
| 69 | (Y., *et al*. 2014) | Grip Strength Measuring Device | Grip Strength | Assessment | Memory Disorders Patients | Hand |
| 70 | (LM., *et al*. 2008) | Magnetic Tracking Device | Kinematic | Assessment | SCI | Shoulder |
| 71 | (A., *et al*. 2020) | Electromagnetic Tracking System | ROM | Assessment | Hand OA | Finger |
| 72 | (ND., *et al*. 2017) | Smart Band | Activity | Assessment | Healthy | Wrist |
| 73 | (NP., *et al*. 2012) | Neuroassess Glove | ROM | Assessment | SCI | Hand |
| 74 | (Bobin., *et al*. 2018) | Smart Cup | Position Grasp Force | Assessment Rehab | Stroke | Arm And Hand |
| 75 | (N and E, 2018) | Myo Armband | Motion | Assessment | Healthy | Arm And Hand |
| 76 | (WY., *et al*. 2020) | Smart Ball and Wearable Motion Trackers | Motion | Assessment | Adolescents With Intellectual Disabilities | Arm |
| 77 | (Mahadevan., *et al*. 2020) | Wrist-Worn Wearable Device | Tremor? | Assessment | PD | Wrist |
| 78 | (JP., *et al*. 2020) | Custom Instrumented Shirt | ROM | Assessment | Shoulder Arthroplasties | Shoulder |

| | | | | | | |
|---|---|---|---|---|---|---|
| 79 | (R., *et al*. 2019) | SEM Glove | Grip And Pinch Strength | Assessment | Functional Finger Disorders | Finger |
| 80 | (LC., *et al*. 2009) | Jar Simulator With One Torque Sensor | Force | Assessment | Healthy | Finger |
| 81 | (Logue., *et al*. 2022) | Custom-Designed Sensorimotor Devices | Grip Force | Assessment | Elder Healthy | Hand |
| 82 | (Sohn., *et al*. 2019) | Portable Motion-Analysis Device (Table) | Trajectory | Assessment Rehab | Upper-Extremity Impairments | Hand |
| 83 | (A., *et al*. 2013) | Electromagnetic Devices | ROM | Assessment | Healthy | Shoulder |
| 84 | (A., *et al*. 2016) | Wearable Inertial Rings and Bracelets | Gesture | Assessment | Healthy | Hand Wrist |
| 85 | (RJ., *et al*. 2015) | Wireless Multi-Sensor Body-Worn Devices | Quantity Of Activity | Assessment | Neurological Patients | Hand Arm |
| 86 | (J., *et al*. 2012) | Sensor-Enabled RFID System | Movement | Assessment | Stroke | Object Hand |
| 87 | (Gracia-Ibanez., *et al*. 2020) | Instrumented Glove | ROM | Assessment | Healthy | Hand |
| 88 | (L., *et al*. 2020) | Tetragrip Is A 4-Channel Surface FES Device | Strength | Train Rehab | SCI Tetraplegia | Total |
| 89 | (Aizawa., *et al*. 2010) | An Electromagnetic 3D Tracking System | ROM | Assessment | Healthy | Total |
| 90 | (RJ., *et al*. 2019) | Glove Orthosis With Motion-Tracking Sensors | ROM | Assessment | Stroke | Hand |
| 91 | (B., *et al*. 2011) | Load Measuring Device | Force | Assessment | Healthy | Hand |
| 92 | (Mohan., *et al*. 2013) | Sensorized Glove | Force ROM | Assessment Rehab Train | Stroke | Hand Object |
| 93 | (Lang., *et al*. 2017) | Accelerometers | Use Of Time | Assessment | Stroke | Wrist |
| 94 | (Lee., *et al*. 2019) | Accelerometers | Activity | Assessment | Stroke | Wrist Finger |
| 95 | (HL., *et al*. 2018) | Accelerometers | Arm Activity | Rehab | Stroke Adult | Hand |
| 96 | (Bezuidenhout., *et al*. 2021) | Accelerometers | Arm Movements | Assessment | Stroke | Total |
| 97 | (FC., *et al*. 2002) | Accelerometers | Activity | Rehab | Healthy | Total |
| 98 | (G., *et al*. 2011) | Accelerometers | Arm Use Duration | Assessment | Stroke | Arm |
| 99 | (E., *et al*. 2015) | Accelerometers | Activity | Assessment | Healthy | Total |
| 100 | (van der Pas., *et al*. 2011) | Accelerometers | Activity | Assessment | Stroke | Arm |
| 101 | (KJ and CE, 2018) | Accelerometers | Activity | Assessment | Healthy | Total |

| | | | | | | |
|---|---|---|---|---|---|---|
| 102 | (S., *et al.* 2022) | Accelerometers | Activity | Assessment | Elder Healthy | Hand |
| 103 | (A., *et al.* 2020) | Accelerometers | Activity | Assessment | DMD | Hand |
| 104 | (Uswatte., *et al.* 2000) | Accelerometers | Activity | Assessment | Healthy | Hand |
| 105 | (GRH., *et al.* 2021) | Accelerometers | Activity | Assessment | Stroke | Hand |
| 106 | (N., *et al.* 2014) | Accelerometers | Activity | Assessment | Stroke | Hand |
| 107 | (ME., *et al.* 2012) | Accelerometers | Activity | Assessment | Stroke | Hand |
| 108 | (RR., *et al.* 2015) | Accelerometers | Activity | Assessment | Stroke | Hand |
| 109 | (A., *et al.* 2016) | Accelerometers | Activity | Assessment | Stroke | Wrist |
| 110 | (E., *et al.* 2014) | Accelerometers | Movement Duration, Peaks, And Jerk Smoothness | Assessment | Stroke | Wrist |
| 111 | (X., *et al.* 2019) | Accelerometers | Activity | Assessment | Healthy | Finger |
| 112 | (CE., *et al.* 2021) | Accelerometers | Activity | Assessment | Stroke | Wrist |
| 113 | (RR and CE, 2013) | Accelerometers | Activity | Rehab | Healthy | Wrist |
| 114 | (G., *et al.* 2006) | Accelerometers | Activity | Assessment | Stroke | Wrist |
| 115 | (MA., *et al.* 2015) | Accelerometers | Activity | Assessment | Stroke | Wrist |
| 116 | (T., *et al.* 2013) | Virtual Environment System | Trajectory Of Movement | Training | Stroke | |
| 117 | (Gurari., *et al.* 2019) | Mechatronic System | Accuracy Strength | Assessment | Stroke | Arm |
| 118 | (Dimbwadyo-Terrer., *et al.* 2016) | VR Systems | ROM | Assessment Training | SCI | Total |
| 119 | (X., *et al.* 2022) | Game Rehabilitation System | ROM | Rehab Training | Stroke | Total |
| 120 | (Dhiman., *et al.* 2018) | VR-Based Adaptive Task Platform | ROM | Train | Stroke | Shoulder |
| 121 | (Zhang., *et al.* 2008) | Interactive Internet-Based System | Motion | Rehab | Stroke | Total |
| 122 | (Adams., *et al.* 2015) | Virtual World-Based System | Motion | Assessment | Stroke | Total |
| 123 | (N., *et al.* 2013) | 3D Electromagnetic System | Movement Precision Velocity Smoothness | Assessment | FRDA | Total |
| 124 | (Malesevic., *et al.* 2021) | Hand Functions Assessment System (BEAGLE) | ROM | Assessment | Stroke | Hand Wrist |
| 125 | (M., *et al.* 2020) | Commercial Head-Mounted Display VR | Movement Performance And Quality/ Kinematic | Rehab | Stroke | Total |

| | | | | | | |
|---|---|---|---|---|---|---|
| 126 | (M., *et al*. 2013) | AR and VR | Range, Speed, And Smoothness Of Movement. | Rehab | Healthy | Total |
| 127 | (M., *et al*. 2021) | D-SORM Platform | | | | |
| 128 | (LA., *et al*. 2021) | Ataxia Instrumented Measure–Spoon (AIM-S) System | Smoothness, Trajectory Length, Duration, And Range Of Motion | Assessment | FRDA | Total |
| 129 | (WY., *et al*. 2020) | Smart Ball and Wearable Motion Trackers | Motion | Assessment | Adolescents With Intellectual Disabilities | Arm |
| 130 | (SI., *et al*. 2018) | Wearable Sensor-Based System | Strength ROM | Training And Rehab | Stroke | Total |
| 131 | (M., *et al*. 2010) | Experimental Home Rehabilitation Station | ROM | Rehab | CP | Hand |
| 132 | (G., *et al*. 2004) | Tracking System | Grip Force | Assessment | Neuromuscular Diseases | Hand |
| 133 | (Yu., *et al*. 2016) | Fusion Of A Gesture Sensor And A Haptic Sensor | Force | Rehab | Disabilities After Neural Injury | Hand |
| 134 | (S., *et al*. 2019) | Mobile Rehabilitation System | Activity | Rehab | Stroke | Total |
| 135 | (Memberg and Crago, 1997) | 1.The Book-Shaped Instrumented Object<br>2.Instrumented Pen/Fork | Hand Grasp Force | Assessment | Healthy | Hand |
| 136 | (Van Der Heide., *et al*. 2017) | MMAAS Motion Capturing Instrument | ROM | Assessment | Healthy | Total |
| 137 | (de los Reyes-Guzman., *et al*. 2017) | Codamotion System Based On Active Markers | ROM | Assessment | SCI | Total |
| 138 | (Song., *et al*. 2022) | Multimodal-Based Movement Training Approach | ROM | Train Rehab | Stroke | Hand |
| 139 | (F., *et al*. 2016) | VR Gaming Platforms | Motion | Rehab | Stroke | Arm |
| 140 | (Bobin., *et al*. 2016) | Platform Consists Of A Smart Cup That Embeds Sensors | Object Position | Rehab Train | Stroke | Arm Hand |
| 141 | (CS., *et al*. 2013) | Computer Gaming | Strength | Train Rehab | RA | Hand |
| 142 | (A., *et al*. 2019) | Leap Motion (LM), Hand Motion Tracking System | Two Hand Coordination | Rehab Train | Multiple Sclerosis | Hand |
| 143 | (Burdea., *et al*. 2010) | Rutgers Arm Ii Rehabilitation System | Strength Rom Velocity Endurance | Rehab Train | Stroke | Total |
| 144 | (Samuel., *et al*. 2015) | VR-Based Therapy System | Trajectory Rom | Train Rahab | Stroke | Total |

| | | | | | | |
|---|---|---|---|---|---|---|
| 145 | (Thielbar., *et al*. 2014) | Actuated Virtual Keypad (AVK) System. | Rom Grip Strength | Rehab Train | Stroke | Hand |
| 146 | (Dimbwadyo-Terrer., *et al*. 2016) | VR Training Based On A Data Glove | TRAJECTORY LENGTH | Rehab Train | SCI | Hand |
| 147 | (W., *et al*. 2020) | System Based On RF Technology | Force Velocity | Rehab | Neuromotor Diseases | Total |
| 148 | (Adams., *et al*. 2018) | VR System (SaeboVR) | Dosages Of Movement | Rehab Train | Stroke | Total |
| 149 | (JY., *et al*. 2021) | VR Rehabilitation System | ROM Accuracy | Rehab | Brain Injury | Total |
| 150 | (Mazzoleni., *et al*. 2009) | Force/Torque Measurements Rehabilitation: Platform | Force | Rehab | Stroke | Finger Arm |
| 151 | (Geijen., *et al*. 2020) | TAAC | Force | Assessment | CP | Arm Hand |
| 152 | (Ricotti., *et al*. 2023) | Wearable sensor | Motion trajectory | Assessment | DMD | Total |
| 153 | (Lee., *et al*. 2023) | VR | Activity | Training | Stroke | Total |
| 154 | (Friesen., *et al*. 2023) | IMU | Motion | Assessment | Healthy | Total |
| 155 | (Koh., *et al*. 2022) | Kinect sensor | ROM | Assessment | Healthy | Total |
| 156 | (Oubre., *et al*. 2022) | Sensor | Activity | Assessment | Stroke | Total |
| 157 | (Choi., *et al*. 2023) | VR with IMU | Accuracy of motion | Training | CP | Total |
| 158 | (Jacob., *et al*. 2023) | Five-finger perturbation system | Force and coordination | Assessment | Healthy | Finger |
| 159 | (N., *et al*. 2023) | Ring-shaped wearable device | Activity | Assessment | Stroke | Hand |
| 160 | (Kamatchi., *et al*. 2023) | VR | Activity | Training Rehab | Stroke | Total |

**Appendix B:** Summary of the included studies

| | Camera-based technology | Sensor-based technology | Combination systems |
|---|---|---|---|
| **Movement** | 1-11,14-29 | 31-36,39,41-43,45,48,52-53,55-56,60-61, 70-71, 73,75-78,82-87,89-90,92,96,110,152,154-155,157 | 116-117,118-129,131,136-139,142-149 |
| **Force** | 3,30 | 40,44,46,64, 66-69,74,79-81,88,91-92 | 117,130,132-133,135,140-141,143,145,<br>150-151 |
| **Daily Activity** | | 37-38,47,49-51,54,57-59,62-63,65,72,<br>93-95,97-109,111-115,156,159 | 134,153,158,160 |
| **Object position** | 11-13 | 74 | 150 |

**Appendix C:** Classification of outcomes based on each technology

| | | Camera-based technology | Sensor-based technology | Combination system |
|---|---|---|---|---|
| **Assessment** | **Diagnostic** | 5,7,11-12,14,16-17,19,21-22,25,27,29-30 | 39-44,47,50-56,69-71,73-74,76-79,85-86,90,93-94,98,100,103,105-110,112,114-115,152,156,159 | 117-118,122-124,128-129,132,137,151,153, |
| | **Effect evaluation** | 1-4,6,8-10,15,18,20,23-24,26,28 | 31-38,45-46,48,57-68,72,75,80-81,83-84,87,89,91,99,101-102,104,111,154-155, | 135-136,158 |
| **Training** | | | 92 | 118,120,140-146,148,157, |
| **Rehabilitation** | | 13 | 49,60,74,82,88,92,95,97,113 | 119,121,125-127,130-131,133-134,138-150,160 |

**Appendix D:** Classification of aims for each technology

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