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Quantifying and Assessing Post-Stroke Patients' Functional Capability Level for Independent Daily Activities: A Review

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ABSTRACT

Every year, over 13.7 million stroke episodes occur worldwide, addressing the pressing need for efficient rehabilitation treatments to restore motor function in stroke patients is paramount. The escalating number of stroke cases emphasises the urgency of developing robust rehabilitation methodologies. Currently, therapists rely on subjective and manual assessments to determine subsequent patient interventions, a method fraught with challenges, including subjectivity and dependence on the therapist's experience. This paper critically reviews the quantification and assessment of post-stroke patients' functional capability for independent daily activities. It delves into the existing standards of clinical assessment, explores the integration of sensors in limb rehabilitation prototypes, and observes the mathematical methods and algorithms employed by previous researchers to assess and quantify stroke patients' functional capability automatically. The discussion covers the advantages and disadvantages encountered in developing these prototypes and evaluating their suitability in addressing the complexities of stroke rehabilitation. In conclusion, this paper provides a perception of existing research and identifies crucial gaps. Based on the current research landscape, it presents proposals for prototype development, paving the way for future advancements in stroke rehabilitation methodologies.

1. Introduction

Stroke occurs due to a sudden interruption of blood flow to a specific part of the brain, resulting in the death of brain cells, as reported by Langhorne *et al.,* and Lo *et al.,* [1,2]. With more than 13.7 million stroke episodes occurring yearly, it has become a significant global concern. Referring to Corrigan *et al.,* [3], Renner *et al.,* [4], Petty *et al.,* [5], Smith & Eskey [6] and Reker *et al.,* [7], there are three main types of strokes: transient ischemic attack (TIA), ischemic stroke, and haemorrhagic stroke. A TIA is a brief stoppage of blood supply to the brain, resulting in no lasting neurological

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shortage. This type of stroke tends to be a sign or warning for future stroke. Ischemic stroke occurs when a blood vessel transporting blood to the brain is blocked, estimated at 87% of all strokes while Haemorrhagic stroke happens when a blood vessel ruptures.

Efficient rehabilitation treatment for restoring motor function in stroke patients is highly necessary, especially given the rising number of stroke cases, as highlighted by Malcolm *et al.,* [8]. The rehabilitation treatment for post-stroke individuals involves a manual assessment of motor function routinely conducted by therapists. This assessment guides subsequent interventions for patients, as evidenced by the study conducted by Housman *et al.,* [9]. However, manual assessments suffer from various issues, being highly subjective and dependent on the therapist's experiences. In an effort to enhance subjects' limb function and reduce treatment costs, current research has converged towards more effective methods, leveraging technological advancements over traditional rehabilitation therapy, as reported by McConnell *et al.,* Frullo *et al.,* and Ates *et al.,* [10-12].

Technological advancements have been utilised to enhance subject engagement in rehabilitation therapy, with the potential to facilitate multiple training sessions and assess the subject's performance throughout the recovery process, as indicated by the research conducted by Frullo *et al.,* [11]. Substantial evidence supports the notion that intensive training involving numerous repetitions can yield improved rehabilitation outcomes, both in each stage of rehabilitation and in long-term treatment. Recent studies, such as those by Pichiorri *et al.,* [13] and Pehivan *et al.,* [14], present various strategies for incorporating technological assistance in rehabilitation, showcasing the ongoing development in this field.

This paper discusses the utilisation of transitive and tool-mediated tasks to assess and quantify the functional capability of post-stroke patients in performing their daily activities. While several clinical assessments, like the box and block test (BBT) and nine-hole peg test (NHPT), focus on general or indirect tasks related to daily living, there are some assessments directly targeting activities of daily living (ADL), such as ABILHAND and the Frenchay Arm Test (FAT). However Cioroiu [15], and Hasiuk *et al.,* [16] argue that the scoring process remains manual and heavily relies on the therapist's experience.

According to Liu *et al.,* [17] grounded in rehabilitation theory, the recovery may span from six months to two years, contingent on the reperfusion of the penumbra area of the brain and the restoration of physical function within this critical period. Consequently, it is crucial to diligently monitor the ability to perform transitive and tool-mediated tasks in daily activities through an objective assessment.

This paper presents a comprehensive review of quantifying and assessing the functional capability levels of post-stroke patients in performing independent daily activities. The organisation of the paper is as follows: Section 2 delves into standard clinical assessment practices for evaluating post-stroke patients' functional capability levels, while Section 3 provides a review of transitive and tool-mediated tasks. Following this, Section 4 elaborates on prototype devices designed for quantifying and assessing patients' functional capability in limb rehabilitation. Section 5 introduces a mathematical method for the quantification and assessment of post-stroke patients' functional capability. Discussions regarding the gaps in this review and recommendations are presented in Section 6 finally followed with a conclusion in section 7.

2. Standard Clinical Assessment Practices for Post-Stroke Patient’s Functional Capability Level

The limb-impaired function is a cause of stroke that can be assessed and treated by rehabilitation therapists throughout the acute and practical rehabilitation recovery based on Chiri *et al.,* [18]. Limb function injuries limit a subject's ability to perform their daily activities and issues with disabilities have been identified as the limb function restoration critical rehabilitation goal. The goal of therapy for subjects with limb difficulties is always to improve motor function in the affected part and to increase the subject's ability to interact successfully in daily activities, as reported by Atashzar *et al.,* [19]. As a result, therapists must use standard assessment tools to measure subject improvement and communicate subject status between treatment sites.

Limb impairment resulting from a stroke is a condition that rehabilitation therapists can assess and treat throughout both acute and practical rehabilitation phases, as indicated by the study conducted by Chiri *et al.,* [18]. Injuries affecting limb function can significantly limit a subject's ability to engage in daily activities and addressing these disabilities is recognised as a critical goal in limb function restoration during rehabilitation. The objective for individuals with limb difficulties is consistently to enhance motor function in the affected area and to improve the subject's capacity to engage successfully in daily activities, as reported by Atashzar *et al.,* [19]. Consequently, therapists must utilise standardised assessment tools to gauge subject improvement and facilitate effective communication about the subject's status across various treatment sites.

While implementing technology for the rehabilitation system, it is significant to understand functional motor assessment for clinical subjects. Several approaches to limb assessments can evaluate the subject's recovery after a stroke. The application used for an assessment must be appropriate and applicable to a wide range of capabilities pursuing stroke and be insightful to the subjects' improved functioning. Ten clinical assessments have been chosen to align with the benchmarks outlined in the functional ability technique for this review. The clinical measures, organised in alphabetical order, are as follows:

2.1 ABILHAND

The ABILHAND is an interview-based assessment tool specifically created to evaluate a patient's perceived difficulty in using their hands for manual activities, as reported by Penta et *al.,* [20]. According to Ashford *et al.,* [21] and Penta *et al.,* [22], this tool assesses both the active function of the upper limbs and the patient's proficiency in performing bimanual tasks, irrespective of the strategies employed to accomplish them.

Tailored specifically for stroke patients, the ABILHAND exclusively includes bimanual items and two alternative unimanual activities that demand adept use of the affected hand, such as cutting and filing nails. Throughout the assessment, patients are prompted to self-assess and rate their perceived difficulty in independently performing these tasks, utilising scoring criteria of 0 for Impossible, 1 for Difficult, and 2 for Easy.

2.2 Action Research Arm Test (ARAT)

The ARAT is developed by Ronald Lyle in 1981 through the adaptation of the Upper Extremity Function Test (UEFT), as reported by RC *et al.,* [23]. He introduced enhancements to the test administration and scoring processes. These modifications resulted in a shorter administration time, simplified procedures, and the organisation of items based on a hierarchical scale known as the Guttman Scale, according to the study conducted by Lang *et al.,* [24]. Recognising the need for more specific instructions regarding the client's position, scoring, and test administration, Yozbatiran *et al.,* [25] proposed a standardised approach to the ARAT.

As reported by Wilson *et al.,* [26] the ARAT comprises 19 items categorised into four subscales: grasp, grip, pinch, and gross movements. Each subscale operates on a hierarchical Guttman scale, where all items are arranged in ascending order of difficulty. In the ARAT, successfully completing the most challenging item within a subscale implies proficiency in the less difficult items within the same subscale, as reported by Daghsen *et al.,* [27]. Conversely, the inability to perform certain items suggests a challenge in completing the more demanding items in that particular subscale.

2.3 ArmBox and Block Test (BBT)

The BBT, as stated by Zapata-Figueroa *et al.,* [28], and Liang *et al.,* [29], measures unilateral gross manual dexterity. It is a quick, simple, and cost-effective test. The original version of the BBT was developed in 1957 by Jean Hyres and Patricia Buhler, with modifications made by E. Fuchs and P. Buhler in 1976. In 1985, normative data for the BBT were established by Mathiowetz, Volland, Kashman and Weber.

According to Liang *et al.,* [29], the BBT consists of a wooden box divided into two compartments by a partition and contains 150 blocks. In the BBT administration, the patient is instructed to move as many blocks as possible from one box compartment to another within 60 seconds. The test commences with the unaffected upper limb, and a 15-second trial period is allowed at the beginning of each side. Prior to the assessment, it is important to inform the patient that their fingertips must cross the partition when transferring the blocks. There is no need to retrieve blocks that may fall outside the box, as reported by Mathiowetz *et al.,* Prochaska *et al.,* and Everard *et al.,* [14,15,32].

2.4 Frenchay Arm Test (FAT)

The FAT, as outlined by Don *et al.,* [33] assesses upper extremity proximal motor control and dexterity during activity of daily living (ADL) performance in patients with upper extremity impairments resulting from neurological conditions. The FAT is an upper extremity-specific measure of activity limitation. Patients sit comfortably at a table during the assessment with their hands on their laps; each test item starts from this position. Patients are then asked to use their affected arm to:

i. Stabilise a ruler while drawing a line with a pencil held in the other hand. The ruler must be held firmly to pass.
ii. Grasp a cylinder (12 mm diameter, 5 cm long), set it on its side approximately 15 cm from the table edge, lift it about 30 cm, and replace it without dropping.
iii. Pick up a glass half full of water about 15 to 30 cm from the table's edge, drink some water, and replace it without spilling.
iv. Remove and replace sprung clothes peg from a 10mm diameter dowel, 15 cm long set in a 10 cm base, 15 to 30 cm from the table edge. To avoid dropping the pegs or knocking the dowel over.
v. Comb hair (or imitate); comb across the top, down the back, and each side of the head.

Each item is scored as either pass (1) or fail (0), and the total scores range from 0 to 5, as indicated by Cioroiu [15]. The administration of FAT typically takes approximately 3 minutes.

2.5 Fugl-Meyer Assessment (FMA)

The FMA, a stroke-specific and performance-based impairment index assessment, as described by Rech *et al.,* [34] is designed to assess motor functioning, sensation, balance, joint range of motion, and joint pain in individuals with post-stroke hemiplegia, as reported by Hijikata *et al.,* [35]. Referring to the study by Gladstone *et al.,* [36] its application extends to determining disease severity, describing motor recovery, and planning treatment assessments. The scale comprises five domains: Motor function, Sensation, Balance, Joint range of motion, and Joint pain, encompassing a total of 155 items based on the study by Kim *et al.,* [37]. Scoring is performed through direct performance observation, utilizing a 3-point scale where 0 signifies inability to perform, 1 denotes partial performance, and 2 represents full performance. The maximum attainable score is 226.

2.6 Motor Assessment Scale (MAS)

The MAS is a performance-based scale designed for assessing everyday motor function in stroke patients. It adopts a task-oriented approach, evaluating functional tasks rather than isolated movement patterns as stated by Carr *et al.,* [38]. According to Malouin *et al.,* [39] the MAS encompasses eight items corresponding to distinct areas of motor function: supine to side lying, supine to sit over the edge of a bed, balanced sitting, sitting to standing, walking, upper-arm function, hand movements, and advanced hand activities. Each task is performed three times, and the best performance is recorded.

According to Miu *et al.,* and Prange-Lasonder *et al.,* [24,25], scoring utilises a 7-point scale ranging from 0 to 6, where a score of 6 indicates optimal motor behaviour. The general tonus item is scored based on continuous observations throughout the assessment. A score of 4 on this item indicates a consistently normal response. Scores above 4 suggest persistent hypertonus, while scores below 4 indicate various degrees of hypotonus.

2.7 Nine Hole Peg Test (NHPT)

The NHPT is developed to quantify finger dexterity, specifically referred to as fine manual dexterity, according to the study by Moreno-Morente *et al.,* [42]. Bertoni *et al.,* [43] reported that the NHPT consists of a square board equipped with nine pegs. One end of the board features holes for the pegs to be inserted, while the other includes a shallow round dish for storing the pegs. During the administration of the NHPT, patients are tasked with removing the pegs individually from a container and placing them into the holes on the board as swiftly as possible. Subsequently, the patient removes the pegs from the board one by one and returns them to the container. The test begins with the unaffected upper limb, as stated by Soiza *et al.,* [44].

To ensure standardised testing conditions, the board is positioned at the client's midline, with the container oriented towards the hand under evaluation. The hand being assessed exclusively performs the test, while the non-assessed hand is allowed to hold the board's edge to provide stability. The score is determined by the time taken to complete the test activity, measured in seconds. The stopwatch is initiated when the patient touches the first peg and concludes when the last peg hits the container as performed by Grice *et al.,* [45] in their study.

2.8 Purdue Pegboard Test (PPT)

The PPT is designed to evaluate fingertip dexterity and gross hand, fingers, and arm movement in patients experiencing upper extremity impairments due to neurological and musculoskeletal conditions as reported by Irie *et al.,* [46]. According to Lindstrom-Hazel *et al.,* [47] originating from the work of Joseph Tiffin in 1948, the PPT serves as a valuable assessment tool.

Based on the report by Rule *et al.,* [48] during the PPT, the patient is comfortably seated at a testing table with the PPT positioned in front. The testing board features four cups across the top and two vertical rows of 25 small holes down the centre. The two outer cups contain 25 pins each; the cup immediately to the left holds 40 washers, and the cup to the right of the centre contains 20 collars. According to the study conducted by Sigirtmac *et al.,* [49], the scoring is based on the number of pins placed within a specified time frame. As Proud *et al.,* [50] mentioned, the patient is allowed three trials for each task following a single demonstration by the therapist.

2.9 Upper Extremity Function Test (UEFT)

The UEFT is an evaluative measure designed to assess upper extremity functional impairment and its severity in patients experiencing dysfunction in the upper extremity, as referenced in the study by Rasool *et al.,* [51]. This test evaluates function based on the premise of intricate upper extremity movements commonly used in daily activities, including supination/pronation, grasp/release, pinch, and grip. Assessing these movement patterns allows for predictions regarding the patient's ability to perform functional activities, as indicated by Alnahdi *et al.,* [52].

According to Alnahdi *et al.,* Aljathlani *et al.,* and Kang *et al.,* [52-54], UEFT is primarily designed to quantify the patient's capacity to execute general upper extremity activities and does not account for skill, speed, range of motion, endurance, and sensation. The scoring system employed by the UEFT is straightforward, allowing for comparisons of results at different time intervals. Scoring involves assigning a value of 0 if the test cannot be performed, 1 for partial completion of the test, 2 if the test is completed but takes an abnormally long time or is done with significant difficulty, and a full score of 3 if the subject performs the test normally.

2.10 Wolf Motor Function Test (WMFT)

The WMFT is a tool designed to quantify upper extremity motor ability by assessing timed and functional tasks, as stated by Turtle *et al.,* [55]. Initially developed in 1989 by Wolf, Lecraw, Barton, and Jann, the original version of the WMFT aimed to investigate the effects of constraint-induced movement therapy in clients with mild to moderate stroke and traumatic brain injury, as reported by Song *et al.,* [56]. In 1999, a graded version of the WMFT is introduced by Uswatte and Taub to evaluate the motor abilities of patients functioning at a lower level, according to *Turtle et al.,* [55].

Referring to Kang *et al.,* [54] the original WMFT comprised 21 items, while the widely used version now consists of 17 items. The first six items involve timed functional tasks, items 7 and 14 serve as strength measures, and the remaining nine analyse movement quality while completing various tasks. Based on Carr *et al.,* and Malouin *et al.,* [22,23] during the assessment, both the patient's less affected and most affected upper extremities are tested.

Table 1 presents an overview of the ten standard clinical assessments discussed. These assessments have been established and utilised over an extended period as benchmarks to determine the stage of stroke or the level of recovery in stroke patients. The manual nature of these assessments involves therapists being actively present to evaluate each activity performed by the patients. However, the manual assessment process introduces specific considerations that warrant attention and further exploration.

Table 1
The clinical assessment for the functional ability assessment benchmarks

Clinical Assessment	Measures	Task	Score	Time taken for normal patient
ABILHAND	The difficulty of using hands to perform manual activities in daily life	23 manuals activities	0 - impossible 1 - difficult 2 - easy	10 minutes
ARAT	Ability to handle objects in different sizes, weights, and shapes.	19 items for grasp, grip, pinch and gross	0-cannot performs 1-partially performs 2-long time to completely performs 3-normally performs	7 to 10 minutes per task
BBT	Unilateral gross manual dexterity	Transfer 150 wooden blocks to another compartment	Based on the number of wooden blocks transferred	1 second per wooden block
FAT	Upper extremity proximal motor control and dexterity	5 items; stabilise, grasp, pick, remove and comb.	0-fail 1-pass	3 minutes per task
FMA	Motor functioning, sensation, balance, joint range of motion and joint pain	155 tasks in 5 domains; Motor function, Sensation Balance, Joint range of motion and Joint pain	0- cannot perform. 1- partially perform 2- fully performs	30 minutes
MAS	Motor function	8 items corresponding to 8 areas of motor function	0-cannot perform 6- optimal motor behaviour	15 minutes
NHPT	Finger dexterity	To fit pegs into holes	Based on the time taken to complete the task. Shorter is better	17 to 20 seconds
PPT	Gross movement of the arm, hand and fingers	Place a pin from a cup on the PPT board	Total pin placed in a column in 30 seconds	5 to 10 minutes
UEFT	The severity of upper extremity impairment	33 items in domain supination/pronation, grasp/release, pinch and grip	0 = cannot perform 1 = task partially complete 2 = task completed in a long time 3 = Performs normally	1 hour
WMFT	Upper extremity	Initially 21, currently 17 for functional, strength and analysing movement quality.	0-cannot performs 1-partially performs 2-performs with assistance 3-performs but slowly 4-performs with a slightly slow 5-normally performs	3 minutes per task

3. Transitive and Tool-Mediated Tasks

Transitive tasks, as referenced in studies by Bondi *et al.*, Wright *et al.,* Bardt *et al.,* Gatti *et al.*, and Stolbkov *et al.,* [59-63], refer to activities or actions that involve an individual or the patient performing a specific action directly on an object or target in daily activities. In the context of stroke rehabilitation, these tasks are aimed at improving motor skills, coordination, and functional abilities following a stroke. Examples of transitive tasks in post-stroke rehabilitation to return to performing Activities of Daily Living (ADL) independently, as reported by Handjaras *et al.,* [64] include:

i. Grasping and manipulating objects where the patients may practice picking up and manipulating objects of different shapes, sizes, and weights to enhance their hand-eye coordination and fine motor skills.
ii. Buttoning clothes where the patient fastens buttons on clothing items helps improve finger dexterity, hand coordination and upper limb control.
iii. Turning pages of a book where the patients may engage in activities that require them to turn the pages of a book, strengthening their grip, forearm control, and hand movements.
iv. Throwing and catching a ball. These activities focus on improving upper limb movement, coordination and motor skills. Patients may practice throwing a ball to a target or catching a ball thrown by a therapist.

While tool-mediated tasks involve using tools or assistive devices to facilitate or enhance specific actions or movements, referring to stroke rehabilitation, these tasks are aimed to provide support, compensate for deficits in motor function and promote independence in daily activities as reported by Camardella *et al.,* Feix *et al.,* Warrier *et al.,* Averta *et al.,* Catrambone *et al.,* and Schwarz *et al.,* [65-70]. Based on Handjaras *et al.,* [64] examples of tool-mediated tasks in post-stroke rehabilitation include [64]:

i. Using adaptive utensils where the patients may utilise specialised utensils with modified handles or attachments to facilitate self-feeding, promoting functional independence and improving hand and arm control during mealtime.
ii. Using a reacher/grabber. This tool helps patients with limited mobility or reduced reach to independently retrieve objects from the floor, shelves, or other distant locations, enhancing their independence and reducing the risk of falls.
iii. Using an assistive device for walking. Patients with difficulty with mobility after a stroke may use devices such as canes, walkers or orthotic braces to support their gait, improve balance, and increase stability while walking.
iv. Using adaptive equipment for bathing or dressing. Various adaptive tools such as long-handled sponges, dressing sticks, or zipper pulls can assist patients in performing self-care tasks, promoting independence and enhancing their ability to manage daily activities.

Transitive and tool-mediated tasks are concluded to refer to any supportive equipment directly used during treatment. The rehabilitation process involving treatment for physical capabilities can be divided into two main categories: physiotherapy and occupational therapy (OT). According to Fransen *et al.,* [71] physiotherapy primarily focuses on diagnosing, treating, and preventing physical impairments, injuries and disabilities. Its main objective is to restore and enhance a person's physical function, mobility and strength. While, referring to Bass *et al.,* [72] OT aims to assist individuals in achieving independence and improving their engagement in daily activities, also known as occupations. Both physiotherapy and OT involve transitive and tool-mediated tasks. However, the majority of researchers tend to focus more on the physiotherapy rehabilitation aspect. There is a notable lack of research conducted in the field of OT.

Several prototype devices designed as transitive and tool-mediated tasks have been created to provide repetitive patient training, aiding in expediting their recovery process. These prototypes are primarily focused on specific body parts and are controlled by actuators that operate in tandem, ensuring the training remains free from injury risks. The efficacy of this training routine is subsequently assessed using established clinical assessment methods.

Moreover, there have been even more advanced research efforts dedicated to crafting prototypes based on standard clinical assessment criteria. These prototypes offer the advantage of generating scores aligned with standardised scales, simplifying the process for doctors or therapists to formulate tailored rehabilitation programs for stroke patients. Due to their score-generating nature, these prototypes incorporate an array of sensors to capture the necessary parameters from stroke patients, thereby determining their level of impairment resulting from the stroke. Subsequently, the sensor-derived data is processed through various methodologies such as statistical analysis, machine learning techniques or rule-based models. This processing enables the automatic generation of a score that aligns with the benchmarks of standard clinical assessments.

4. Prototype Device as Transitive and Tool-Mediated Tasks for Quantifying and Assessing Patient’s Functional Capability in Limb Rehabilitation

The intersection of transitive and tool-mediated tasks plays a significant role in both rehabilitation domains, namely physiotherapy and occupational therapy (OT). The discussion begins with exploring prototype development within the framework of physiotherapy. As emphasised earlier, physiotherapy is primarily focused on the diagnosis, treatment, and prevention of physical impairments, injuries, and disabilities. Its principal goal is to restore and enhance an individual's physical function, mobility, and strength without explicitly referencing the activity of daily living (ADL) [71].

Researchers Threatt *et al.,* [73] and Lu *et al.,* [74] have contributed significantly to this domain by designing innovative solutions. They have developed two distinct robotic devices namely the Assistive Robotic Table (ART) and the Rehabilitation Robotic Device (RRD). Both these devices are centred around upper limb training, a crucial aspect of stroke rehabilitation. The ART employs a pneumatic cylinder and pressure as controlled parameters, while the RRD is powered by a DC motor that utilises torque control. Although both actuator types serve their respective purposes, pneumatic actuators are favoured for prolonged usage due to their extended lifespan, making them particularly suitable for repeated applications. Initial testing of these prototypes has been conducted. The ART has undergone trials with three stroke patients, and further testing is planned with a larger patient group. Conversely, the RRD has been assessed with four healthy subjects, with Lu *et al.,* [74] earmarking future testing with stroke patients as part of their ongoing work. These initiatives signify substantial progress in upper limb rehabilitation, with the potential to significantly impact patient outcomes.

The subsequent prototypes category delves into finger rehabilitation, presenting a promising avenue in comparison to alternative methodologies. Makhdoomi *et al.,* [75] have made a substantial contribution in this domain by successfully designing a finger rehabilitation device. This prototype incorporates a wire-driven extension and flexion mechanism actuator to govern the subject's finger movement. Significantly, the design places a strong emphasis on ergonomic considerations and integrates cost-effective components. The utilisation of a wire-driven actuator offers distinct advantages, characterised by high efficiency and the provision of torque assistance with a predefined maximum torque limit during training sessions. This meticulous design approach aligns effectively with the requirements of finger rehabilitation. Furthermore, Patar *et al.,* [76] have developed the Pneumatic Actuator Finger Exoskeleton (PAFEx) as another prototype in finger rehabilitation. This device employs a pneumatic actuator with pressure as the controlled parameter. The pliable nature of pneumatic actuators renders them particularly suitable for this application. The design incorporates a slight margin of movement beyond the set pressure, satisfying well to the needs of stroke patients. Notably, both prototypes have been tested exclusively with healthy subjects, pointing out the need for further exploration involving stroke patients to validate their efficacy in a clinical context. These initiatives highlight the growing potential of specialised prototypes in addressing finger rehabilitation's complex demands and promise improved patient outcomes.

Continuing the discussion, Ji *et al.,* [77] introduced a novel Reconfigurable Magnetic Sensing System prototype. This innovation is specifically designed for upper and lower limb training, focusing on monitoring parameters such as asymmetrical seat reaction and foot plantar force characteristics during the walking motion of stroke patients. Particularly, this prototype has been subjected to experimental evaluation, marking a significant step towards its potential effectiveness. However, further testing involving actual stroke patients is required to validate its applicability in a clinical context.

The discussed prototypes in the context of physiotherapy have been summarised in Table 2. It's important to note that these prototypes are primarily developed for training and do not incorporate an assessment function. Furthermore, they do not explicitly adhere to any standardised clinical assessment protocols. The continuous efforts within this field indicate that innovative measures have been implemented to enhance rehabilitation methodologies, with the potential to significantly influence the quality of care and outcomes for stroke patients.

Table 2
Physiotherapy developed prototype

Researcher	Focus Limb	Prototype Developed	Controlled Actuator Type	Subjects
Threatt *et al.*, [73]	Upper limb	Assistive Robotic Table (ART)	Pneumatic pressure	3 stroke patients
Lu *et al.*, [74]	Upper limb	Rehabilitation Robotic Device (RRD)	DC motor torque	4 healthy subjects
Makhdoomi *et al.,* [75]	Finger	Finger rehabilitation device	Wire-driven extension and flexion mechanism	Nil
Patar *et al.,* [76]	Finger	Pneumatic Actuator Finger Exoskeleton (PAFEx)	Pneumatic pressure	4 healthy subjects
Ji *et al.,* [77]	Upper and lower limb (while walking)	Reconfigurable magnetic sensing system	No actuator. The prototype is reading the walking character	Nil

The subsequent phase in enhancing the prototype for the transitive and mediated-tool task involves integrating an evaluation mechanism. This step should adhere to standards clinical assessment to compute scores or gauge functional capabilities accurately. Various sensor types have been utilised to capture the requisite limb parameters. Table 3 provides a compilation of research that focuses on the utilisation and advancement of sensors for the automatic quantification and evaluation of patients' capabilities.

Table 3
A compilation of research that focuses on the utilisation and advancement of sensors to quantify and appraise the capabilities of patients automatically

Researcher	Sensor Type	Measured Parameter	Subjects	Clinical Assessment
Wang *et al.,*[78]	Reflective marker	Kinematic and muscular level	15 Healthy subjects 15 Stroke patients	Brunnstorm, FMA, MAS
Boukhennoufa *et al.,* [79]	IMU	Tri-axial linear acceleration and tri-axial angular velocity at a frequency of 50Hz	30 Healthy subjects	Nil
Li *et al.,* [80]			1 healthy subject 1 stroke patient	WMFT
Bisio *et al.,* [81]	MoCap (SmartPANTS)	Three Cartesian coordinates, limb rotation and force	1 Healthy subject	Nil
Weiss *et al.,* [82]	Camera or Image processing	Position, direction and length of the finger	3 Stroke patients	Nil
Ma *et al.,* [83]		Hand extent of reach and movement speed DARAS	1 healthy subject 1 stroke patient	Nil
Moore *et al.,* [84]		Body motion (DARAS), DS5 depth sensor	1 Stroke patients	Nil
Li et *al.,* [85]		Hand gestures	50 Stroke patients	Brunnstorm, FMA

Wang *et al.,* [78] utilised reflective markers to gauge stroke patients' kinematic and muscular aspects. The experiment focused on established clinical assessments such as Brunnstrom, FMA and MAS. By conducting tests on 15 healthy individuals and 15 stroke patients, they concluded that the data derived from these parameters is precise and reliable. Consequently, this method demonstrates advantages in evaluating a patient's functional capacity. However, there is a concern that excessive use of reflective markers coupled with entangled wires might lead to patient discomfort during exercises.

To undertake these limitations, Boukhennoufa *et al.,* [79] and Li *et al.,* [80] embraced the utilisation of Inertial Measurement Unit (IMU) sensors. The distinct advantage of IMUs lies in their compact and adaptable design. Each IMU sensor unit functions as both a gyroscope and an accelerometer. This strategic approach reduces the necessity for complex wiring, thus amplifying comfort levels for individuals recovering from strokes. In their respective investigations, Boukhennoufa *et al.,* [79] conducted experiments involving a group of 30 stroke patients, whereas Li *et al.,* [80] ran their research on a single healthy subject and one stroke patient.

Harnessing the benefits of IMU sensors, Bisio *et al.,* [81] integrated multiple IMU sensors with pressure sensors to develop a motion capture (MoCap) system known as smartPANTS, which stands for Smart Physical Activity and Neuro-motor Training System. smartPANTS has the capability to deliver insights related to three Cartesian coordinates, limb rotation, and force measurements. Its integration of wireless and Internet of Things (IoT) functionalities adds to the efficacy of the proposed smartPANTS solution. It's crucial to ensure proper and tidy management of sensors in contact with the skin to prevent any potential discomfort for stroke patients.

The subsequent approach involves utilising a camera or image processing technique to gather data about limb movement. This non-contact method employs sensors that do not require physical placement on the limb, eliminating potential discomfort that could impact the assessment. This marks another progression in sensor application. Weiss *et al.,* [82] employed the Leap Motion sensor to capture parameters such as finger position, direction, and length. On a similar note, Li *et al.,* [85] expanded the use of Leap Motion sensors by incorporating virtual reality gaming functionalities, leveraging their findings in conjunction with the Brunnstrom and Fugl-Meyer Assessment (FMA). Their research incorporated data from 3 and 50 stroke patients, respectively.

Ma *et al.,* [83] and Moore *et al.,* [84] have pioneered the creation of a daily activity recognition and assessment system (DARAS) through the utilisation of the DS5 depth sensor as their core technology. Employing video analysis techniques, they extract essential parameter data. Ma *et al.,* [83] concentrate on monitoring hand movements and their velocity during kitchen-related activities. In contrast, Moore *et al.,* [84] extend their scope to encompass entire body movements during outdoor activities. Notably, both of these research endeavours have undergone testing with individual stroke patients for validation.

The ultimate advancement in enhancing the prototype for the transitive and mediated-tool task encompasses the ongoing development of sensors, employing hardware or prototype device. Among these, exoskeleton-type prototypes have garnered significant attention. These prototypes can be further expanded by incorporating the Assist-As-Needed (AAN) function. A basic configuration is the one-degree-of-freedom (1-DOF) robot, which involves a motor as an actuator and a built-in torque sensor. Drawing from the MAS assessment, Ahmad *et al.,* [86] have substantiated the efficacy of their prototype through experimentation involving two stroke patients. Similarly, Mounis *et al.,* [87] have extended their prototype to a 2-degree-of-freedom(2-DOF) robot, enabling a broader range of angles for assessment. Following the same principle, Mounis *et al.,* [88] christened their prototype, The Upper Limb Rehabilitation Exoskeleton, complete with AAN functionalities. Their prototype design is rooted in established clinical assessment standards and underwent testing with stroke patients, as depicted in Table 4.

Table 4
A comprehensive overview to encapsulate the entire discussed research

Prototype type	Researcher	Name	Parameter Measured/ Sensor	Clinical Assessment	Subjects
Exoskeleton	Ahmad *et al.*, [86]	1-DOF robot	Torque and angle	MAS	2 stroke patients
	Mounis *et al.*, [87]	2-DOF robot	Torgue, angle and IMU	WMFT	7 healthy subjects 3 stroke patients
	Mounis *et al.*, [88]	The upper limb rehabilitation exoskeleton	Torque, strain, angle	ARAT, WMFT	15 stroke patients
	Tsai *et al.,* [89]	DexoHand	Output voltage, cable tension	MAS	6 healthy subjects 18 stroke patients
	Chua *et al.*, [90]	VASST II	Hall effect, foot	6MWT, 10MWT, BBS, FAC	11 stroke patients
Soft wearable device	Poliero *et al.*, [91]	XoSoft	Torque, angle, power, flexibility	Nil	1 healthy subject

					1 stroke patient
Brain–computer interface	Chen *et al.*, [92]	BCI-FES system	EEG amplifier with 32 electrodes	FMA, Kendall MMT, MBI	32 stroke patients
Mechanisation standard assessment	Hsiao *et al.*, [93]	Digital BBT	Overhead depth camera	BBT	Nil
	Hsu *et al.*, [94]	CERB	Pinch force	PPT, JTHF	14 stroke patients
Joystick	Peng *et al.*, [95]	CASIA-ARM	Rotary encoder, torque, force	FMA	24 stroke patients
Smart device	Bobin *et al.*, [96]	Smart cup; SyMPATHy	Conductive electrode, force, IMU	ARAT	9 stroke patients

Tsai *et al.,* [89] focused their investigation on finger rehabilitation, creating the DexoHand prototype. Notably intricate and smaller, this prototype hones in on finger functionality. They employ output voltage and cable tension as measurable parameters using the cable-driven actuator concept. The prototype's efficacy was evaluated through testing involving six healthy individuals and 18 stroke patients.

On a different note, Chua *et al.,* [90] undertook a study centred on walking rehabilitation, culminating in developing The Variable Automated Speed and Sensing Treadmill II (VASST II). Distinguished by its sturdiness and modification from traditional treadmill functionality, it features an added robust frame for suspending a sling to support the patient's weight. This prototype is enriched with a hall effect and foot sensors to gauge walking capabilities. A cohort of 11 stroke patients tested this innovation’s functionality.

Poliero *et al.,* [91] also revolved around advancing a soft wearable prototype. In contrast to conventional exoskeletons that typically incorporate programming for Assist-As-Needed (AAN) functions capable of providing full assistance, the XoSoft prototype takes a unique direction. Its primary objective is to alleviate the limb's workload by 10% to 30%, making it suitable for everyday activities. To determine the appropriate level of support, this prototype strategically adjusts parameters such as torque, angle, power, and flexibility.

Separate from mechanical support approaches, Chen *et al.,* [92] investigated an alternative strategy employing functional electrical stimulation (FES) technologies. Their work involved developing a brain-computer interface (BCI) that analysed EEG signals recorded via 32 electrodes. The resulting output was then transmitted to an FES rehabilitation device. This research incorporated data from 32 stroke patients and was grounded in clinical assessments such as FMA, Kendall Manual Muscle Testing (MMT), and Modified Barthel Index (MBI).

Furthermore, apart from creating prototypes as supportive equipment, prototypes are also designed to mechanise existing clinical assessments. Hsiao *et al.,* [93] introduced a novel approach with the development of a Digital BBT. This was achieved by incorporating an overhead depth camera onto the BBT assessment workstation to facilitate score calculation. This method is particularly suitable as it eliminates direct contact between the sensor, subject and object being assessed. By doing so, the discomfort caused by entangled wires and sensors is mitigated effectively. A comparable methodology was also adopted by Hsu *et al.,* [94], who designed a Computerized Evaluation and Re-education Biofeedback (CERB) prototype. Based on the PPT and the Jebsen-Taylor Hand Function (JTHF) assessment, this prototype evaluates the subjects' pinch force. In the CERB prototype’s testing phase, 14 stroke patients participated in validating its functionality.

Continuing, a joystick-type prototype named CASIA-ARM was developed. Peng *et al.,* [95] spearheaded this effort, blending joystick controls with virtual gaming functionalities. The CASIA-ARM prototype is geared explicitly towards shoulder and elbow rehabilitation, aligning with the standards of the FMA and featuring AAN capabilities. The prototype underwent testing with a group of 24 stroke patients to validate its effectiveness.

In a distinctive departure from the aforementioned prototypes, Bobin *et al.,* [96] introduced an alternative innovation; a smart device named SyMPATHy, depicted as a smart cup. This unique creation amalgamates conductive electrodes, force sensors, and Inertial Measurement Units (IMUs). Developed around the Assessment of Motor and Process Skills (AMPS) assessment, SyMPATHy provides insights into its orientation, liquid level, positioning relative to a reference target and even tremors. An initial study involving nine stroke patients was conducted to assess its viability. A comprehensive overview is available in Table 4 to encapsulate the entire discussed research.

All the discussed research on developing prototypes for transitive and tool-mediated tasks aims to quantify and assess patients' functional abilities in limb rehabilitation. However, it seems that only the physiotherapy aspect of rehabilitation has been addressed. According to the author's best knowledge, the development of prototypes for another segment of rehabilitation, namely Occupational Therapy (OT), which focuses on aiding individuals in achieving independence and enhancing their participation in daily activities, is rarely discussed. This underscores a research gap that presents an opportunity for future exploration.

5. Mathematical Method to Quantify and Assess Post-Stroke Patient Functional Capability

Functional capability is an individual's ability to carry out activities and tasks, assessed through established clinical evaluation methods [97]. Determining functional capability is crucial for tracking a patient's recovery progress or assessing their level of disability. Additionally, it furnishes therapists with valuable insights to tailor appropriate patient treatment plans. Evaluating post-stroke patients' functional capability using the discussed transitive and tool-mediated task prototypes employs various techniques. These techniques differ based on the chosen clinical assessment standard [88], the developmental stage of the prototype or sensor and the data derived from prototype usage. This segment explores mathematical approaches to quantify and assess post-stroke functional capability.

AL-Fayyadh [98] employed statistical analysis to discern disparities in stroke self-efficacy levels across pertinent variables. Rather than employing parametric statistical tests, the Mann–Whitney and Kruskal–Wallis tests were utilised. These non-parametric tests are employed to gauge distinctions between groups or samples. The advantage of this method is the flexibility to be used in many kinds of categorical and interval data, making them a valid choice for fulfilling research activities. Through this methodology, AL-Fayyadh [98] achieved objective research to evaluate stroke self-efficacy of poststroke patients and identify the differences in stroke self-efficacy levels among some relevant variables based on the Glasgow Coma Scale.

The subsequent approach involves graph plotting and fitting the data with a line of best fit. Li *et al.,* [80] adopted this method, plotting data collected from multiple wireless IMU sensors during various activities. They utilised the Least Square (LS) method to derive estimations. A limitation of this technique is its reliance on the assumption of linearity, which may not always hold true. However, judging from the plotted data, the estimation through the LS method seems to be appropriate. In contrast, Mounis *et al.,* [88] employed the Z-spline function to fit data derived from torque sensors and rotary-type potentiometers. This Z-spline method offers improved estimation grounded in three distinct conditions derived from clinical data. The reliability and consistent real-time calculation of this method enable the AAN controller to effectively furnish torque support following the individual's functional capability level.

Another method involves comparing or benchmarking the patient's data against a healthy subject or unaffected limb. Mounis *et al.,* [97] adopted this approach by comparing IMU sensor parameters between stroke patients and healthy subjects, using a normalisation function to align the two datasets. This technique ensures consistency in calculating the functional capability of stroke patients, suggesting its suitability as an estimation method. However, the normalisation function might not be feasible for real-time implementation. Similarly, Poliero *et al.,* [91] utilised a healthy subject's torque (TH) as a reference to determine the required assisted torque (TA) for a stroke patient (TS) using the equation TA = TH – TS in their XoSoft prototype. XoSoft effectively reduced the mechanical energy demand for stroke patients by 10% to 30% and enhanced gait stability and endurance. However, XoSoft is most applicable to stroke patients who have regained some power or are in the advanced stages of recovery, as around 70% of the effort still needs to be contributed by the patient.

A unique method involving the conversion of sensor data into image data proves beneficial in mitigating the challenge of limited data availability. Boukhennoufa *et al.,* [79] have effectively utilised this approach, where IMU data was transformed into image data through the Gramian Angular Field (GMAF) algorithm. This image data was then processed using a Convolutional Neural Network (CNN), a model well-established for image classification. Despite having a relatively small dataset of only 30 subjects, their method achieved an impressive accuracy rate of 98.53%. However, it's worth noting that this calculation approach could become more complex and necessitate substantial data storage.

Ma *et al.,* [83] who converted video data into image data, employed a similar concept of utilising CNN's effectiveness in image analysis. Leveraging the Convolution-De-Convolution (CDC) method, they successfully developed a Daily Activity Recognition and Assessment System (DARAS) capable of categorising daily activities within natural home environments. Additionally, it quantitatively evaluated upper body motions using depth videos. The recognition accuracy rates for simulated and real-life videos reached 90.9% and 87.5%, respectively. The remarkable feature of DARAS is that the sensors remain non-contact, ensuring patient comfort. However, it's important to enhance the algorithm to accommodate multiple subjects during activities, as post-stroke patients should refrain from undertaking activities of daily living (ADL) in isolation.

A similar strategy was adopted by Hsiao *et al.,* [93] who employed a filtering method to refine images captured by a depth camera in their Digital BBT. These processed images provided insights into hand movements and the box during the assessment. Subsequently, scores were automatically calculated from these processed images with an accuracy rate of up to 91%.

Another approach involves using the Fourier transform, which converts time-domain signals into the frequency domain. This method was employed by Bobin *et al.,* [96] in their inventive cup prototype known as SyMPATHy. By analysing data from conductive electrodes, force sensors, and IMU sensors, they identified specific frequency components associated with distinct hand movements or gestures, allowing them to recognise particular actions. The outcomes of their study demonstrated the remarkable potential of SyMPATHy for integration into therapy sessions, attributed to its simple, compact, and dependable design. However, it was noted that adjustments to the rim cup design are necessary to ensure ease of use for stroke patients.

The final method discussed in this section involves machine learning. Wang *et al.,* [78] conducted a comparison of three machine learning techniques, support vector machine (SVM), back propagation neural network (BPNN) and random forest (RF) as classifiers for kinematic data and surface electromyography (sEMG) signals from reflective markers. The results indicated that the functional capability output was reliable and consistent, with SVM achieving the highest accuracy at

92.82%, followed by RF at 88.66% and BPNN at 88.19%. While the calculation yielded promising results, using numerous reflective markers in this experiment and the potential for tangled wires could lead to patient discomfort.

Similarly, Bisio *et al.,* [81] employed the RF machine learning technique as a classifier for IMU and force sensor data placed on the thigh, shin, and foot. The RF model was trained on a 66% data split and their prototype, named SmartPANTS, achieved an impressive 99% accuracy in real-time movement analysis. With such high accuracy and equipped with Internet of Things (IoT) functions, further alignment of SmartPANTS' activities with standard clinical assessments could enhance its potential as a viable rehabilitation tool.

Furthermore, Weiss *et al.,* [82] utilised the K Nearest Neighbour (K-NN) technique to characterise hand movements using the Leap Motion sensor. This technique proved effective, achieving a 90% accuracy rate in 60 trials. However, training sessions using this system, which relies solely on the Leap Motion sensor, still require close monitoring by healthy individuals due to the free movement of limbs. Physical support may be necessary to complete the system effectively.

The algorithms and mathematical methods utilised by the previously mentioned researchers in their limb rehabilitation prototypes are summarised in Table 5. These prototypes, designed to assess and measure patients' capabilities, hold significant potential for application within medical facilities and rehabilitation centres. Their importance becomes particularly evident in addressing the shortage of therapists and the rising number of stroke patients, which is a challenge in many countries. Additionally, these prototypes offer a potential solution to the subjectivity and dependency on therapists' expertise in clinical assessment scoring. With technology's progression, these prototypes can incorporate supplementary features such as AAN controllers and telerehabilitation. This integration of algorithms or mathematical methods for evaluating and quantifying patients' capabilities can substantially enhance stroke patients' recovery process.

Table 5
Summary of the mathematical method used to assess and quantify post-stroke patient’s capability in limb rehabilitation

Method	Researcher	Calculation	Achievement	Advantage
Statistical analysis	AL-Fayyadh [98]	Mann–Whitney test and Kruskal–Wallis test. Both non-parametric statistical tests are used to analyse the differences between groups or samples	Evaluate stroke self-efficacy of poststroke patients and identify the differences in stroke self-efficacy levels among some relevant variables	The fixability to be used in many kinds of categorical, as well as interval data can make them a valid choice for fulfilling research activities
Best fit graph	Li *et al.,* [80]	The data from IMU sensors have been plotted, and the estimation is achieved using LSM.	Multiple channels of wireless IMU systems are developed	Less wire and sensor since IMU carry multiple signals.
	Mounis *et al.,* [88]	Data from torque sensors with strain gauge mechanism and rotary-type potentiometers for angle reading are analysed using the Z-spline function	AAN torque as per functional capability required.	Support torque is consistently calculated in real-time.

Benchmark to healthy subject	Mounis *et al.,* [97]	The parameter from IMU sensors is compared between stroke and healthy subjects using the normalisation function.	The position, velocity, and time data from stroke patients is normalised to healthy subject	Consistency in the patient's level of disability indicates the suitability of this estimation technique
	Poliero *et al.,* [91]	The reference torque comes from a healthy subject (TH) and provides assisted torque (TA) required by the patient (TS). TA = TH - TS	Body movement reading provided by motion capture and XoSoft system gives the torque assist required.	Reduce 10% to 30% stroke patient mechanical energy requirements and improve gait (stability and tiredness)
Image data conversation	Boukhennoufa *et al.,* [79]	CNN – converts the IMU data to image data using the GMAF algorithm.	Reach max accuracy of 98.53%	Converting to data overcomes fewer data issues.
	Ma *et al.,* [83]	CDC- classify daily activities in natural home environments and quantitatively evaluate upper body motions by utilising depth videos	Recognition accuracies for simulated and real-life videos reach 90.9% and 87.5%, respectively	The sensor is not touching the patient.
	Hsiao *et al.,* [93]	The filter method has been used to clean 100-frame images from a depth camera. The processed image provides info on hand movement and box during the assessment.	The score has been automatically calculated from the process image.	The sensor is not touching the patient.
Fourier Transform	Bobin *et al.,* [96]	Converting the time-domain signals to the frequency domain, the specific frequency components related to different types of hand movements or gestures for the recognition of specific actions.	SyMPATHy has excellent potential to be used in therapy sessions.	A simple, compact and reliable device was developed.
Machine learning	Wang *et al.,* [78]	SVM, BPNN, and RF as classifiers for kinematic data and surface electromyography(sEMG) signals	Accuracy of SVM-92.82%, BPNN – 88.19% and RF – 88.66%	Consistent and reliable results accomplished
	Bisio *et al.*, [81]	RF training to 66% of split as a classifier to IMU and force sensor placed to tight, shin and foot.	99% accuracy to natural time movement.	The SmartPANTS is equipped with IoT, allowing tele rehab function.
	Weiss et al., [82]	K-NN methodology is implemented for characterising the hand movement from the leap motion sensor.	90% accuracy from 60 trials	Quantitative and medically assisted rehabilitation through low-cost technology

6. Discussion

The objective of stroke rehabilitation is to resume motor function in stroke patients, enabling them to perform their everyday tasks autonomously. Research efforts have been undertaken to create prototypes for transitive and tool-mediated tasks. These efforts have developed from basic training prototypes, progressing to incorporating and enhancing sensors, culminating in comprehensive prototypes equipped with assessment capabilities.

To ensure the optimal effectiveness of the developed prototype, it is imperative to minimise sensor complexity and eliminate complex cable arrangements, especially when positioned on the patient's body. Such arrangements frequently result in discomfort and anxiety, primarily due to the risk of short circuits leading to electric shocks. Moreover, these setups can accidentally impact the outcomes of experiments. In line with technological advancements, sensors have undergone improvements, encompassing wireless capabilities, multi-parameter readings, and integration with the Internet of Things (IoT), among other features. The utilisation of sensors with such capabilities not only reduces reliance on physical sensors but also reduces the need for wiring, thereby enhancing the overall comfort of stroke patients.

Furthermore, the utilisation of sensors in isolation, lacking in suitable guidance or at the very least, an assessment or training framework, proves to be less efficient. This is because stroke patients often require assistance with their movements, contingent upon the severity of their stroke. Consequently, a therapist or another assisting party is frequently necessary to facilitate ongoing activities. This highlights that the initial objective of reducing the dependency on therapists or assistants for conducting assessments and training has yet to be fully realised. Ideally, any prototype conceived and developed should incorporate built-in support mechanisms or, at the very least, the capability to guide stroke patients through the required activities. This would ensure stroke patients receive the necessary guidance and assistance to perform tasks more independently.

The assistance of cameras for monitoring stroke patients represents a commendable approach. It is an advancement over the conventional method of employing multiple sensors attached to the patient's body, often accompanied by tangled wires. By capturing readings without direct skin contact and utilising precise calculation methodologies, patient parameters can be effectively assessed during evaluation and training sessions. Importantly, this approach maintains the patient's comfort throughout these activities. However, it's crucial to acknowledge that continuous monitoring may infringe upon patient privacy. The constant presence of monitoring cameras might be intrusive, and stroke patients should not be subject to continuous surveillance. To address this, the use of cameras for assessing and training stroke patients should incorporate a predefined time limit and be under the patient’s control, ensuring their consent and preserving their autonomy in the monitoring process.

While numerous studies have indicated the potential of prototypes as valuable rehabilitation tools in hospital and rehabilitation centre settings, it's important to note that not all researchers have conducted tests with actual stroke patients. In general, the development of any prototype should involve testing sessions with both healthy subjects and subsequently stroke patients, given that the intended beneficiaries are stroke patients. The absence of testing results involving stroke patients could raise doubts about the effectiveness of each developed prototype. To establish credibility and verify the utility of these innovations, it is crucial to carry out comprehensive testing with the target audience, ensuring that the prototypes effectively cater to the unique needs and challenges faced by stroke patients.

Recent research highlights that the most developed prototypes are not closely aligned with activities of daily living, despite the rehabilitation goal is enabling stroke patients to independently perform their daily activities. Researchers often emphasise general activities like most standard clinical assessments. Similarly, standard clinical assessments typically have a broad focus and may not specifically address activities of daily living. In hospitals and rehabilitation centres, patients achieving high scores after training sessions commonly undergo additional training using a manipulation board, which serves as a rehabilitation workstation. The manipulation board is considered an excellent candidate for enhancement in prototype development due to its direct focus on daily living activities and has been established in hospitals or rehabilitation centres. This focus also aligns with the Motor Activity Log (MAL) assessment, despite its initial development without adherence to any specific standard. Fundamentally, the activities facilitated by the manipulation board aim to enable stroke patients to achieve independence in their daily lives.

7. Conclusion

This paper provides a critical review of an assessment and quantification approach for evaluating the functional capabilities of post-stroke patients as they engage in transitive and tool-mediated tasks within their daily activities. The perception of functional capability levels is associated with standardised clinical assessments, serving as valuable tools for doctors and therapists to assess the condition of stroke patients and formulate appropriate rehabilitation plans. This paper offers a thorough examination of 10 commonly utilised standards of clinical assessment and their applications in pertinent research.

The inherent subjectivity in these assessments, relying heavily on therapists' expertise for scoring, often leads to discrepancies in evaluations from different practitioners, a challenge frequently encountered in rehabilitation settings. To address this issue, integrating transitive and tool-mediated tasks as rehabilitation aids emerges as a solution. By offering consistent and ongoing training sessions for limbs affected by stroke, prior studies have explored using specialised sensors to capture movement data. This data is then harnessed to assess and quantify patients' functional capabilities automatically. Over time, designs have evolved, transitioning from wired sensors attached to the body to wireless solutions incorporating IoT functionalities. Particularly, recent iterations priorities patient comfort, incorporating sensors that do not directly contact the skin.

The computation of a stroke patient's score or functional capability relies on factors such as the prototype's state of development, patient parameters, sensor technology and the chosen standard clinical assessment. Diverse methods have been employed, encompassing statistical analysis, best-fit graphs, comparison to healthy subjects as benchmarks, Fourier transforms, and machine learning which has gained significant traction among researchers. Each approach demonstrates its strengths and limitations, contributing to a landscape ripe for innovation as researchers refine prototypes and attempt for more robust outcomes.

Concluding this paper, the discussion section highlights several research shortcomings and gaps. For instance, the potential utilisation of manipulation boards for transitive and tool-mediated tasks is outlined as a topic warranting exploration in future studies. These emphases the ongoing pursuit of enhancing rehabilitation methodologies to serve the needs of post-stroke patients better.

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