Review Article

Devices That Measure and Improve Grip Strength Through Telerehabilitation: A Scoping Review

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Article info:
Received: 16 Oct 2022
Accepted: 14 Feb 2023

Citation: James S, Karunakar E, Conrad M, Sengupta S. Devices That Measure and Improve Grip Strength Through Telerehabilitation: A Scoping Review. Journal of Modern Rehabilitation. 2024; 18(3):?-?

Running Title: Devices to improve grip strength

Abstract

Background: Grip strength is a vital hand function skill required to perform everyday tasks. Diseases and conditions deteriorate grip strength. Repetitive exercises can improve grip strength, but people are non-compliant with home exercise programs. Gamification of exercises can increase home exercise compliance. A device is needed to measure and rehabilitate grip strength remotely to deliver exercises remotely. A preliminary search on that topic did not provide any review literature on grip strength devices. The aim of this scoping literature review (SLR) was to explore various electronic devices and sensors used to measure grip strength.

Methods: Five electronic databases - PubMed, IEEE, Scopus, ACM digital library, and Web of Science, were searched for this review. Modified preferred reporting items for systematic literature review (SLR) and Meta-Analyses (PRISMA) guidelines were used, with

Population/Disease, Intervention, Comparison, Outcome (PICO) employed to identify keywords and frame research questions.
Results: The results of the search yielded 3,546 articles, and after elimination, 15 articles met the inclusion criteria for review. This scoping review has categorized various devices and sensors that measured grip strength, along with their wireless communication and gamification capabilities.
Conclusion: The categorization presented in this review can help researchers to use this information for future directions by emphasizing research gaps and design telerehabilitation devices.
Keywords: Hand strength, smartphone, telerehabilitation, video games; stroke, muscle strength dynamometer

Introduction

People with weak handgrip strength experience difficulty in performing everyday tasks, such as opening a door, holding a glass of water, and carrying a grocery bag. Certain diseases and conditions can deteriorate a person's grip strength to the extent that they cannot feed themselves. Studies show that physical exercise can strengthen weak muscles, thus improving grip strength (1). When people perform handgrip exercises repeatedly, they their grip strength can improve (2,3). While therapists often provide home exercise instructions in a paper format, people often fail to comply with exercise prescriptions because of boredom, repeated movements performed with no goals, and lack of supervision.

Recent technological advances, "telerehabilitation," provide an alternative way to deliver rehabilitation at a distance. Exercises are delivered through a gamified environment, making the exercises enjoyable, goal-oriented, and supervised at a distance. If therapists want to monitor grip strengthening exercises via telerehabilitation, an electronic device is required to measure grip strength remotely. To make telerehabilitation effective, the person participating in the therapy should play games to improve grip strength using the same device and a therapist needs to be able to monitor a patient's progress remotely and adjust their goals. In a review article, Innes (4) listed different devices to measure grip strength and included a section on electronic devices under strain gauges, but those devices did not have telerehabilitation capabilities. At this time, the types of devices or sensors that are available to measure grip strength remotely and allow monitoring exercises at home were not found in the literature. For these reasons, a scoping review was conducted to systematically map research done in this area, as well as identify existing gaps in knowledge. In addition to the knowledge gap, the authors also identified limitations such as existing reviews identify telerehabilitation as communication by phone, video conferencing, virtual reality programs, and robotic devices – all of these devices addressed gross motor movements rather than grip strength alone. A need exists to survey existing innovative devices that measure grip strength using telerehabilitation.

In this scoping literature review (SLR), the authors present a comparative analysis of different sensors and devices explicitly used for grip strength measurements. This SLR highlights future directions by emphasizing research gaps. Since a need exists to survey innovative devices used for handgrip strength measurement and improvement, the SLR aims to find telerehabilitation devices specifically used to measure and improve grip strength.

Methods

Kitchenham and Charters' (5) modified preferred reporting items for SLR and meta-analyses (PRISMA) guidelines for software engineering practices were adopted for this SLR. The SLR is divided into three phases: (a) planning, (b) conducting, and (c) reporting. In the planning phase, the need for this review is identified, with aims and objectives defined, and objectives framed into research questions. The search and selection process strategies were planned. In the conducting phase, the articles found in the search and selection process were reviewed. The included primary articles found during the conducting phase were analyzed using a thematic analysis to extract and synthesize the data. During the reporting phase, the extracted data were included in the results section and various themes needed to answer the research questions were synthesized in the discussion section. Suggestions based on the findings were made for future research on telerehabilitation for hand grip strength.

Research Aims, Objectives, and Questions

The SLR aims to survey various electronic devices and sensors explicitly used to measure grip strength and the device's capability to improve grip strength through gamification via telerehabilitation. The SLR's aim was divided into four research objectives (RO1-RO4) before the review process, with four research questions (RQ1-RQ4) developed that were based on each objective see search strategies (Table 1).

Table 1. ***Research Objectives and Research Questions***

RO #	Objective/Explanation	RQ #	Research Questions
1.	Develop an understanding of different types of existing devices used to measure grip strength and different sensors used, and study the different systems or methods to measure and capture grip strength data electronically	1.	What are different sensors used in electronic devices that measure grip strength?
2.	To determine if the device has wireless capabilities (e.g., Bluetooth, Wi-Fi, Zigbee, or NRF technologies) that can be used to build gamification systems	2.	Which of these devices have wireless capabilities?
3.	Game-based rehabilitation can have benefits if these devices have gaming capabilities	3.	Which of these available devices can be gamified?
4.	Determine if these devices can be used in clinical studies to measure their efficacy in grip strength in rehabilitation	4.	What types of clinical studies have been used to evaluate the effectiveness of these devices?

Search Strategies

Databases in medical and engineering domains were searched using the Population/Disease, Intervention, Comparison, Outcome (PICO) method (Table 2) (6). Keywords were identified to get the desired search results and address the research questions. Boolean operators were used in the search process to obtain optimized results, with search results limited to only English language articles, full-text availability, peer-reviewed journals, and conference proceedings (7). The search was restricted to the last 10 years because of substantial improvements in communication and information technologies, as well as the advent of telerehabilitation.

Initially, we performed a preliminary search in google scholar with the keywords “telerehabilitation” and “grip strength,” resulting in more than 600 articles. We found some systematic reviews and meta-analyses (8–12) in telerehabilitation for upper extremities. Approximately 120 articles that were included in the systematic reviews for devices used in grip strength were evaluated. The rehabilitation technologies in these reviews were used primarily to improve the overall gross upper extremity movements resulting from stroke rather than specifically focusing on decreased grip strength resulting from a variety of different diseases and conditions. The authors observed limitations of the previous systematic reviews, which included:

1. Telerehabilitation typically used communication by phone, video conferencing, virtual reality programs, and robotic devices. These devices addressed gross motor movements rather than focusing on grip strength.
2. No reviews were identified devices and sensors that were explicitly used for grip strength
3. Innes investigated commercially available devices but a very few telerehabilitation technologies existed at that time.

So for these above reasons, the authors conduct a scoping review with the aims to survey the various electronic devices and sensors explicitly used to measure grip strength and the device’s capability to improve grip strength through gamification via telerehabilitation.

Table 2. ***Search terms using the PICO method***

Search terms	Parameter	Research Questions and Explanation	Keywords searched
S1	Population	**RQ1.** Are the available devices used in any clinical studies?	“stroke” OR “brain injury” OR “weakness” “OR “paresis” OR “poor grip strength” OR “weak grip” OR “hemiplegia” OR “neurological disorder” OR “carpal tunnel syndrome” OR “CTS” OR “musculoskeletal.”
S2	Intervention	**RQ2.** Are those available devices gamified?	“smartphone” OR “computer” OR “mobile” OR “robot” **OR** “game*” OR “game-based” OR “gamified” OR “Kinect” OR “virtual reality” OR “augmented reality”
S3	Context	**RQ3**. Do these devices have wireless capabilities?	“telemedicine” OR “telerehabilitation” OR “telerehab” OR “telestroke” OR “teleneurology” OR “telemedicine” OR “telecare” OR “telehealth” OR “telediagnosis” OR “telemonitor” OR “teletherapy” OR “telehomecare” OR “teleconsultation” OR “remote consultation” OR “remote supervision” OR “remote

			monitoring" OR "remote evaluation" OR "e-health" OR "e-therapy" OR "e-diagnosis" OR "e-intervention" OR "internet-based" OR "televideo" OR "video-teleconference" OR "televideo" OR "video consultation"
S4	Outcome	**RQ4.**What are the different sensors used in electronic devices that measure grip strength?	"device" OR "devices" OR "dynamometer" OR "force sensor" OR "load cell" OR "measure" OR "measurement" OR "electronic" OR "digital" OR "wireless" OR "Bluetooth" OR "Bluetooth" OR "technology" OR "communication" OR "remote"

Selection Criteria – Inclusion and Exclusion

The inclusion and exclusion criteria were predefined prior to conducting the search. Articles are included in the study if they had at least one criterion listed in the inclusion criteria. If an article had any or all of the exclusion criteria, it was excluded. Using these criteria, selection bias could be reduced by identifying primary studies that met the predefined the selection criteria (Table 3).

Table 3. ***Predefined Selection Criteria Identifying Primary Studies***

Predefined Selection Criteria
Inclusion Criteria (At least one) 1. Include the study that uses a novel device to measure grip strength. 2. The device should have electronic capabilities. 3. The device can be used for the healthy population and disease conditions. 4. The device can be used for playing games.
Exclusion Criteria (None) 1. The review will exclude studies related to the robotic hand grasp. 2. The review will exclude commercially available dynamometers (e.g., JAMAR, Baseline, Rolyan, and Martin Vigorimeter). 3. No-pinch strength devices or finger dexterity devices 4. Camera-based hand tracking devices 5. No prosthetic or orthotic devices 6. No hand glove systems or hand exoskeletons

Task Allocation and Assignment

The initial search was performed from November 13 to November 22, 2021, using five databases: Pubmed, Scopus, IEEE, ACM digital library, and Web of Science. The citations with abstracts were downloaded into the Mendeley Desktop (v1.19.8) reference manager. After duplicate entries were removed, two authors (EK and SJ) independently screened the titles and abstracts based on the predefined selection criteria, to find relevant articles for this review. The third author (MC) resolved the difference of opinions, with a consensus reached on the included articles.

Results

This section presents the search results and discusses different devices and sensors for measuring handgrip strength.

Included Studies

Search filters, including studies should be published in peer-reviewed journals, conference proceedings, and published in English from 2012 to 2021, were used to limit the number of studies.. The search resulted in 3,546 items. After applying the filters listed above, 2,711 items were removed. After screening the 835 remaining titles and abstracts for relevance, 201 articles were retained for full-text retrieval. These articles were reviewed using the inclusion and exclusion criteria. A total of 186 articles were removed, leaving 15 articles (13 -27) that were considered relevant for this scoping analysis. (Figure 1)

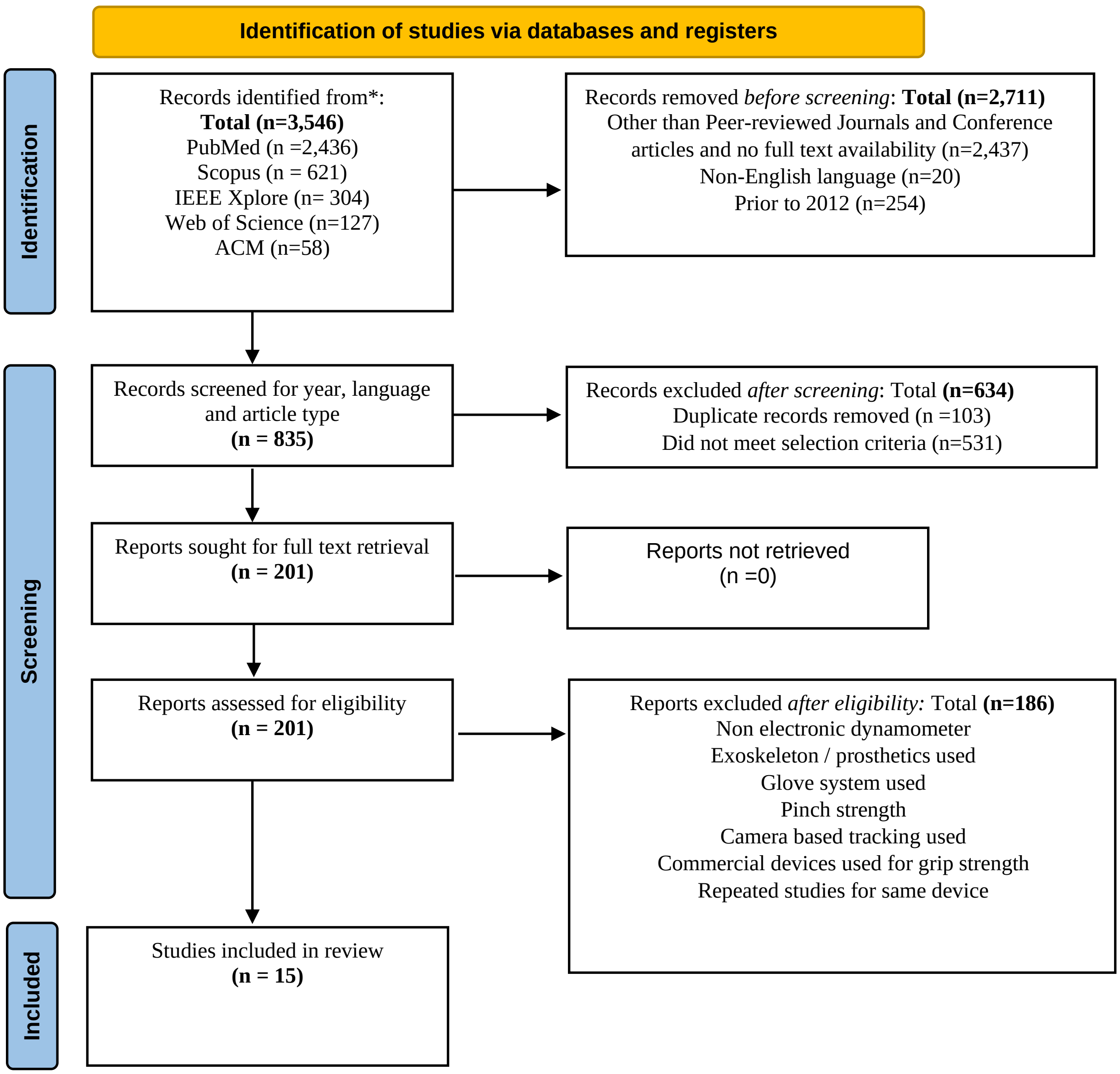

Figure 1. ***Study Flow Diagram***

Data Extraction Process

During the planning stages of this review, the data extraction format was predefined in a Microsoft Excel sheet. The first author independently extracted the initial data, and later the data was reviewed and added by the second author. The predefined Excel sheet had headers for the article's information, including the author's name, year published, and journal's name. We also extracted the device characteristics, such as the name of the device, if it was mentioned; sensor type; if it had any wireless capabilities; if the article mentions any games to play with the device, and also if the study mentions any patients or healthy subjects to test the device.

Findings

This section presents the results of this scoping review's search results. The search yielded 15 articles that met the inclusion and exclusion criteria. Of this number, 7 were published in conference presentations, and 8 were published in peer-reviewed journals. This review aims to survey various existing sensors used to measure grip strength; we did not describe the sensors and their characteristics in detail; the reader is encouraged to explore them with the provided links.

Types of sensors Used for Grip Strength Measurement

At least one article was published every year regarding these grip strength devices. Out of 15 devices, 5 studies used load cell strain-gauge type sensors, 4 used pressure-based sensors, 2 used resistive type sensors, 1 each used a fiber Bragg grating sensor, displacement sensor, capacitive and piezoresistive sensors. Table 4 presents results of these studies

Table 4. ***Studies with Title, Publication, and Population in which Grip Strength was Measured***

Author, Year	**Sensor Types**	**Sensors**	**Device name**	**Wireless capability**	**Gaming Capability**	**Microcontroller & Signal Acquisition & Sampling**	**Study Population**
Noh, 2016. (13)	Load cell - Strain-gauge	N-type strain gauge Strain Gauge Based Force Sensor	Novel device - Hand Dynamometer	Possibility mentioned	Not Mentioned	Arduino Uno R3 & AD524	25 Healthy adults
Jaspers, 2018. (14).		Compressive force sensors (Measurement Specialties FC22) - 0-23Kg accuracy	GriFT (Grip Force Tracking device) - cylindrical dynamometer	Not Mentioned	Yes	NI-DAQ USB-6009	196 Children
Roman, 2020. (15)		PW6KRC3 and PW2F-2 - Strain Gauge type	Grip Force Tracking System (GFTS)	Bluetooth	Yes	Digital Signal Controller PW2F-2	2 Healthy Subjects
Vu, 2018. (16)		Vernier HD- BTA Strain Gauge	BiGRA	Not Mentioned	Yes	National Instrument NI USB-6009 DAQ	6 Young Adults 6 Old Adults 6 Adults with Stroke
Rinne, 2016. (17)		Flexible Metal Blade System Strain Gauge type	Adapted Power-grip controller	Bluetooth	Yes	Not Mentioned.	87 Stroke Subjects
Salaffi, 2021. (18)	Resistive-type	5 FSR 402 –Force Sensor	Innovative Cylindrical shaped device	Not Mentioned	Not Mentioned	Arduino Mega 2560	186 Rheumatoid Arthritis patients

Park, 2013. (19)		an FSR-402 by Interlink	a hand grasp rehabilitation device	Not Mentioned	Not Mentioned	TMS320F2801 digital signal processor (DSP).	2 Healthy Subjects and one stroke
Jaber, 2012. (20)	Pressure-based	MS5535C - Pressure Sensor Intersema Sensorielle SA.	Grip-Ball	Bluetooth	Possibility mentioned	PIC 18LF13K22 & 15 Hz	No Subjects
Mohan, 2013. (21)		MPXM2202A - Pressure Sensor, Freescale Semiconductor	Sensorized ball	Not Mentioned	Possibility mentioned	PIC 18LF4620 CMCdaq	2 Healthy Subjects
Burdea, 2019. (22)		Pressure sensor	BrightArm duo	Not Mentioned	Yes	Not Mentioned	2 Stroke subjects
Park, 2019. (23)		Pressure Sensor	TPS100 System	Bluetooth	Yes	Not Mentioned	50 Stroke
Pani, 2014. (24)	Piezoresistive	Flexiforce A201- a Piezoresistive force sensor by Tekscan	Flexiforce	GSM/GPRS module	Not Mentioned	MSP430FG4618 150 Hz	10 Rheumatoid Arthritis and 10 Systemic Sclerosis
Chethana, 2020. (25)	Fiber Bragg Grating sensor	Fiber Bragg Grating sensor	Fiber Bragg Grating sensor-based Hand Grip Device	Not Mentioned	Not Mentioned	FBG interrogator (SM i130-700 and 1KHz	10 Healthy Subjects
Hoffman, 2017. (26)	Displacement	Displacement Sensor	MediSens Handgrip device	Not Mentioned	Not Mentioned	MSP 430 32Hz	17 Spinal cord injured subjects
Geman, 2016. (27)	Capacitative based	three capacitive force sensors	A novel device	Not Mentioned	Not Mentioned	AD7746 capacitance to digital converter	

Load cell – Strain-gauge type sensors. A load cell is a force-transducer, a piece of metal with a strain gauge attached. This type of sensor transforms any mechanical force, (e.g., a load, weight, tension, or compression) into another measurable physical variable, usually an electrical signal. The electrical signal changes proportionally to the force applied to the sensor. Load cells are susceptible to tiny changes of force. Typically a feeble grip strength of approximately 1 to 2 pounds of force is not easily measured with a standard JAMAR dynamometer from its mechanical dials. In this review, we listed the different types of load cells, from commercially available to patented ones used by various researchers such as

- N-type Strain Gauge Based Force Sensor,
- PW6KRC3 is a single-point load cell by HBM (Datasheet:(28)),
- Vernier HD- BTA Strain Gauge (Datasheet: (29))
- Rinne et al. (17) have a patented force-sensing mechanism called Flexible Metal Blade System. (US Patent document:(30)

Resistive type sensors. Force Sensitive Resistor (FSR) is a variable resistor that changes its resistance depending on the force applied. These sensors are relatively affordable and straightforward for use in applications, but their responsiveness changes slightly from sensor to sensor. So, when using FSRs, a range of responses should be expected. In the case of grip strength, even slight variations (about 0.5 to 1 lbs.) do not make significant clinical differences (31). Two research groups, Park et al. (19) and Salaffi et al. (18) have used this sensor. The Salaffi group designed a cylindrical hand dynamometer and used 5 separate FSRs for individual fingers.

- Interlink 402 –Force Sensor (datasheet:(32))

Piezoresistive type sensors. Piezoresistive sensors also are called “Quartz Force Sensors.” This type of sensor is used to measure force in dynamic applications. Load cell type sensors are used for static applications. The quartz force sensors have quick response, durability, and toughness comparable to solid steel, extended ranges, and the ability to measure quasi-static forces. A hand gripping force is applied to the quartz crystal sensor, producing a proportional voltage signal. Some piezoresistive sensors used in the review were:

- Flexiforce A201- a Piezoresistive force sensor by Tekscan (Datasheet: (33)
- FC22 Compressive force sensors by Measurement Specialties (Datasheet:(34)

Pressure type sensors. Pressure-based force sensors are usually made as single monolithic silicon chip type sensors with a diaphragm and strain-gauge for pressure detection. Some chips come with integrated electronics, such as a multiplexer, analog to digital converter, digital filters, and memory.

- MS5535C - Pressure Sensor Intersema Sensorielle SA (Datasheet:(35)
- MPXM2202A - Pressure Sensor, Freescale Semiconductor (Datasheet:(36)

Capacitive type. Capacitive are also called “Force sensing Capacitors.” They change their capacitance when a force or stress is applied to the sensor. This change of capacitance is measured using capacitance to digital converters. Geman et al. (27) used three capacitive force sensors to develop a novel device to measure grip strength in peripheral neuropathic patients. The study did not mention any specific manufacturer for the sensors, but a commercially available capacitive force sensor was added to the datasheet for reference. (Datasheet:(37)

Displacement sensor. The displacement sensor is used to measure the distance between an object and the sensor. One research group [24] developed a spring-loaded dynamometer with a displacement sensor attached to one of its handles. They calculated the grip strength by detecting the displacement between the stationary and moveable handles and converting it into a distance. Using the distance moved, they converted the distance into grip force using Hooke’s law [F= (-k)(x)]. Again, Hoffman et al. (26) did not mention displacement sensors used in their novel device. Different types of displacement sensors (e.g. optical, linear proximity, and ultrasonic displacement sensors) are available commercially.

Fiber Bragg grating (FBG) sensor. The fiber Bragg grating sensor also is called an “Optical Strain-gauge.” This sensor is constructed using an optical fiber, where a microstructure grating is present within the core of the optical fiber. When light is passed through microstructure grating, a specific light is reflected. When a force, such as a grip strength, is applied to its handles, a slight shift will occur in the reflected light’s wavelength. One research team in India developed a dynamometer to measure grip strength using this FBG sensor (25).

Device Handle Profiles

The scoping review identified studies had used various handles for grip strength measurement devices. Three types of device handles were profiled in the selected studies. Each of these device handles are described.

*Cylindrical profile***.** The commonly used device handle is the cylindrical-shaped handle; with 6 of 15 studies (13–15,18,25,26) using this type of handle. They mentioned that commercially available dynamometers, such as JAMAR and Takei, have a straight profile handle that does not ergonomically fit the natural shape of the hand. The dynamometer handle movement only allows the fingers towards the palm, causing possible inaccuracies in measuring the grip strength.

Spherical profile. The spherical profile is the second most commonly used handle profile. Three studies (20–22) used ball-type profiles, and two used variations of this type – pear-shaped and bulb-shaped profiles.

Straight profile. Most commercially available hand dynamometers use straight profile handles. They have two handles – one fixed and another moveable. A mechanism is present between these two, such as a spring, hydraulic cylinder, or load cell sensor.

Wireless Networking Protocols

A wireless network protocol should be used when delivering or collecting data through telerehabilitation. Devices such as this handgrip dynamometer should use Bluetooth communication between the nodes for a faster and smoother data flow. Our review identified four studies that used Bluetooth to send data from the sensor to the computer or data acquisition system. One study (15) mentioned using the HC-05 Bluetooth transceiver module for sending and receiving data from the sensor to the computer. HC-05 module has a small footprint and consumes low power, and it can be embedded into the dynamometer housing. HC-05 module establishes a serial port connection with the host computer. The other research study (24) have used GSM/GPRS for data transfer.

Gaming Capabilities

In making games for play with the gripping device, the device should have wireless capabilities to provide telerehabilitation services. The games should be easily playable and winnable with little effort to make the rehabilitation program more successful (38). We found eight studies incorporated gaming capability, and four studies had both gaming and wireless communication capabilities. Jaspers et al. (14) developed a portable grip force tracking system (GRIFT) to quantify mirror movements in children. The GRIFT system was incorporated with a computer game, with a goal of jumping an astronaut over meteorites flying across the screen. When the individual squeezes the GRIFT system with either hand, the system gets active and controls the position of the astronaut on the screen. A higher grip strength force moves the astronaut higher on the screen to avoid collision with the meteorite. In this way, they were able to repeatedly engage the individual in squeezing the hand gripper to measure the mirror movements. The experiment done by Rinne et al. in 2016 (17)was similar to the movement of an object on the screen; where they controlled the vertical movement of the object using the grip strength analog signal.

Jaber's (20) team mentioned the possibility of adding "serious games" to this system so that the grip ball could motivate a user to do exercises when linked to the gaming system. They also added that the grip ball could evaluate the grip strength remotely. Another team from India (21) also mentioned using virtual reality games to engage the patients in therapy. In a study done by Roman et al.(15), the subject squeezes a cylindrical hand dynamometer to manipulate the movement of a bullet on the screen to move through a ring. Subjects get visual feedback on the force exerted using the device based on the bullet's movement. Subjects also perform a cognitive task with a level of grip strength applied to the device. They designed this graphical user interface with LabView.

Vu et al. (16), designed a system to assess grip strength sustainability and coordination for both hands. To measure grip strength, their team designed a game-like interface in LabView. When the left-hand dynamometer is squeezed, the target (a "red ball" on the screen) moves vertically and the ball falls if there is no grip signal. The right dynamometer's grip strength signal can move the ball horizontally to the right, and if no signal is received, it will move left. The ball will be in the original spot when there is no force signal from either dynamometer. The subject must squeeze both dynamometers simultaneously to bring the ball to the target location. A visual trace and feedback are seen on the screen.

Burdea and his team (22) developed custom rehabilitation games using the Unity3D game engine, making it easy to play with the remaining skills. The games were made winnable by all by calibrating baseline grip strength prior to gameplay. They used 25% baseline for momentary grip and 10% of maximum grip strength for sustained activities during the game and manipulated the game avatars and objects.

Clinical Conditions

We saw those neurological conditions (e.g., stroke, spinal cord injury, amyotrophic lateral sclerosis, and musculoskeletal conditions such as rheumatic arthritis, carpal tunnel syndrome, and muscular dystrophy) were common conditions in which grip strength was affected. One of the 15 studies did not mention experimental subject testing (20), while others had at least two subjects. A study by Jaspers et al. (14) assessed children's (n = 196) grip strength, and others used adult subjects. Among experimental subjects, diagnoses included stroke (n = 146) in five studies (16,17,19,22,23), rheumatoid arthritis (n = 196) in two studies (18,24), spinal cord injuries (n = 17) (26), systemic sclerosis (n = 10) (24), muscular dystrophies (n = 5) (27), amyotrophic lateral sclerosis (n = 5) (27), and five carpal tunnel syndrome (n = 5) (27).

We classified the intended usages of the handgrip devices. Two studies (19,23) were focused on using the devices for treatment only, with six studies (13,14,16,18,25,26) designed for assessment of handgrip strength . The remainder of the seven studies were intended for both evaluation and treatment of grip strength (15,17,20,21,22,24,27).

Discussion

In this scoping review, the research questions were addressed on use of hand grip strength sensors for telerehabilitation. We examined research articles that focused on different types of sensors used in handgrip measurement devices. The different types of sensors used in handgrip devices, handle profiles, wireless and gaming capabilities and their use in gaming and for handgrip evaluation and treatment were categorized. Based on findings, there appears to be no affordable or integrated systems available to provide grip strength assessment, home treatment with customized games, and remote monitoring by a therapist. Further research is needed to determine the feasibility of this type of integrated system could be developed to deliver customized exercise programs to patients remotely via telerehabilitation.

Conflicts of Interest

"None declared."

Funding

This research did not receive any grant from funding agencies in the public, commercial, or non-profit sectors.

Authors' contributions

All authors equally contributed to preparing this article

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