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Text Network-Based Method for Measuring Hand Functions in Degenerative Brain Disease Patients

Cholzi Kang [1], Jaehoon Kim [1], Hosang Moon [1,*] and Sungtaek Chung [2,*]

[1] Department of IT Semiconductor Convergence Engineering, Tech University of Korea, Siheung 15073, Republic of Korea
[2] Department of Computer Engineering, Tech University of Korea, Siheung 15073, Republic of Korea
* Correspondence: hosang0815@tukorea.ac.kr (H.M.); unitaek@tukorea.ac.kr (S.C.)

Abstract: In this study, we collected various past study results on tools and analytical methods for measuring hand functions of patients with degenerative brain diseases, such as Parkinson's disease and stroke, and selected and proposed appropriate hand function measurement tools, methods, and analysis software based on text network analysis. We searched the literatures using keywords related to degenerative brain disease and stroke patients for participant types, use of devices and sensors for the intervention types, and hand function assessment for measurement types. Among the 2484 literatures collected, 19 were eventually selected based on certain inclusion and exclusion criteria. As a result of text network analysis, the degree-centrality and the betweenness centrality were the highest in the keyword of Parkinson's disease for the participant type, force sensor for the intervention type, and finger tapping for the measurement type. Based on these results, pinch gloves comprising an FSR sensor were manufactured, and software and contents were implemented to measure and analyze various quantitative parameter values during finger tapping. The software can evaluate endurance and agility by measuring the finger-tapping intensity and operation time using the index finger and thumb. The contents can evaluate the stability of hand functions by analyzing the coefficient of variation of the tapping interval, the average contact time, and the accuracy of hand functions by analyzing the reaction rate to the presented visual stimulus. As a result of comparing hand functions through 10 types of analysis parameters with a sample of 12 ordinary subjects (8 men and 4 women) using the manufactured pinch gloves, there was a difference between the two genders in the items evaluating muscle strength and agility, and a significant difference in the analysis parameters evaluating stability and accuracy. The results indicate that using the text network analysis-based hand function measurement tool and the method proposed in this study should help derive the objective research results as well as a quantitative comparison of research results of various researchers.

Keywords: finger tapping; text network; gloves; pinch; degenerative brain disease; serious game

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1. Introduction

The incidence of degenerative brain diseases have increased in recent years with increase in ageing of global population. Such diseases cause disorder of motor control ability, cognitive function, perceptual function, sensory function, and autonomic function due to reduced or lost function of nerve cells constituting the brain [1,2]. Degenerative brain diseases are generally known to include various dementia diseases, such as Alzheimer's dementia and vascular dementia, as well as stroke and Parkinson's disease. In stroke and Parkinson's disease, the upper limb and hand show functional limitations in daily life. In particular, stroke patients' hand function is characterized by reduced hand grip strength, power control, accuracy, reduced independence of finger movements, slowed finger movements, and deteriorated regularity. Parkinson's disease patients are known to have symptoms such as rigidity and akinesia [3,4]. Since most patients' decline in hand function results in varied performance abilities, studies of hand function measurements and improvement makes analysis possible quantitatively [5].

With the development of sensor technology, various sensors have been employed to measure the hand functions of the patients quantitatively. For example, Keisuke Shima et al. (2019) attached magnetic sensors to the distal end of the index finger and thumb and analyzed 12 indicators, such as FT interval and maximum amplitude of finger-tapping movements, to determine the degree of movement disability of patients with Parkinson's disease [6]. In addition, David Vera Anaya et al. (2021) proposed a device based on a flexible triboelectric nanogenerator sensor composed of aluminum electrodes to evaluate finger and hand motion and stiffness as well as wrist and arm tremor. It was verified that the sensor of the proposed device can be classified from 'normal' state to 'moderate' state by evaluating hand movement, finger tapping, and motion, and can be used for quantification and diagnosis of Parkinson's disease [7]. Qianqian Yang et al. (2019) measured grip control using a grip dynamometer with four force sensors to quantitatively investigate the changes caused by aging and stroke in humans and modeled the basic mechanism for motor behavior [8].

Moreover, many studies have attempted to provide new medical solutions by applying new technologies in the IoT industry and VR game tools as a rehabilitation method to improve the hand function of stroke patients [9,10]. Nizan Friedman et al. (2014) fabricated a glove using conductive fibers and produced an isometric grip training protocol linked to a music-based computer game. They found that the rehabilitation training test using the glove resulted in significant improvement compared to the existing treatment method for the hand function test of picking up small objects (measured by B&B score and 9HTP) [11]. Octavian Postolache et al. (2021) fabricated a wearable glove-type device with IMU and flexion sensors, and attached to a VR serious game via force sensors to create a system that can manage and visualize the training effect of rehabilitation. The system was used to evaluate the upper limb's motor ability from the total number of balls caught, the score from the can drop, the number of balls used, and the score obtained as the indicators [12].

Most studies on hand functions verified hand function by measuring and analyzing specific parameters. However, since these studies were conducted on individual parameters separately, it cannot be said that the ability to perform hand functions was evaluated accurately. In other words, measuring various parameters and comparing their influence rather than evaluating the influence of the individual parameter is more important in establishing an effective strategy for restoring hand function in patients with brain diseases.

In the current work, we extracted those parameters frequently used when measuring patients' hand functions through data mining from studies related to hand function and proposed a quantitative measurement method using them. In addition, a simple rehabilitation training method was proposed through the production of hand exercise aids and rehabilitation content design linked to them.

2. Methods and Materials

2.1. Search Strategy for Published Literatures

To search for research literatures related to hand function, we selected academic databases frequently used in academic research and analyzed parameters for measuring hand functions by searching for relevant literatures of a specific period that showed recent research trends and then removing duplicate literature. Academic databases, viz. Web of Science, PubMed, and Embase were used. The parameters for measuring the hand functions were then analyzed based on the literatures published up to December 2021. The keywords for the literature search strategy were divided into participant type, intervention type, and measurement type. Table 1 shows the keywords used for the search.

We included keywords such as Parkinson's, stroke and brain disease for participant type. As keywords for intervention type, we included as many literatures as possible that used sensor* or device*, but excluded those that verified the effect of drug medication on upper limb function improvement. We also included literatures on hand function measurements, such as finger tapping, finger pinch, finger strength, hand strength, and hand grip as measurement types, and excluded those that used the keywords, such as foot and gait which were related to lower limb functions even if they were included in the participant and intervention types.

Table 1. Searching Strategy and Keywords.

DB: Web of Science, PubMed, Embase
Years of research searched: December 2021
Limits: English Language, SCI
Search Equation: (A AND B AND C)

A (Participants)	B (Interventions)	C (Measurements)
parkinson's/ stroke/ brain disease/	sensor*/ device*/ **NOT** drug/	finger tapping/ finger pinch/ finger strength/ hand strength/ hand grip/ **NOT** foot/ gait/

2.2. Inclusion and Exclusion Criteria

Studies: The present study included only articles written in English were included, and those written in other languages or whose type of paper was conference, review, dissertation, and thesis were excluded. In addition, literatures of which the full-text could not be collected were excluded. There were no restrictions on the design of clinical trials, and literatures without clinical trials were excluded.

Participants: Literatures in which the subjects consisted of patients with degenerative brain diseases were included. Cases in which the subjects are nonhuman or consist only of healthy or patients unrelated to degenerative brain disease (i.e., cervical spondylotic myelopathy, cerebral infarction, spastic quadriplegia, traumatic brain injury, fracture, spinal cord injury, rheumatoid arthritis, etc.) were excluded. Moreover, literatures of a sufficient number of participants were included to derive statistically significant results, and those that consisted of less than 10 patients with degenerative brain disease were excluded.

Interventions: Literatures that measured the hand function of subjects using sensors or devices in contact with the body were included. Cases in which sensors or devices are not used as intervention methods, such as watching recorded videotapes or qualitative measurements, used contactless sensors (i.e., Kinect, magnetic, infrared, camera, etc.), and automatically controlled hand function using a robot were excluded. Furthermore, literatures that verified the effect of improving upper extremity function by taking antiparkinsonian agents such as l-dopa and L-dopa were excluded.

Measurements: The body parts to be measured were limited to the hands and fingers, and cases in which measure other upper extremity functions such as wrists, elbows, and shoulders, or lower extremity functions such as foot and gait, were excluded. In addition, literatures that measured biosignals such as electroencephalogram and electromyogram were excluded.

Outcomes: We included literatures studied with the aim of quantitative analysis of finger tapping, pinch strength, and hand grip were included. Cases in which lifting and moving objects or evaluating the coordination ability of both hands were excluded. In addition, literatures studied with the purpose of evaluating a sensor self-developed and comparing its performance were excluded.

2.3. Keywords Classification and Literatures Identification

Figure 1 shows the process of selecting the literatures finally included to analyze the text network in this study. First, The number of literatures collected via the above-mentioned search methods was 784 from Web of Science, 858 from PubMed, and 842 from Embase, totaling 2484 publications. Out of these, 753 literatures obtained from two or more academic databases bore the same title and authors and were considered duplicates, The duplicates were excluded, and the final number of selected literatures was 1731. We reviewed the title and abstract of the identified literatures, excluded those that did not meet the literatures search criteria and selected 363 literatures related to hand function using sensors in patients with brain diseases.

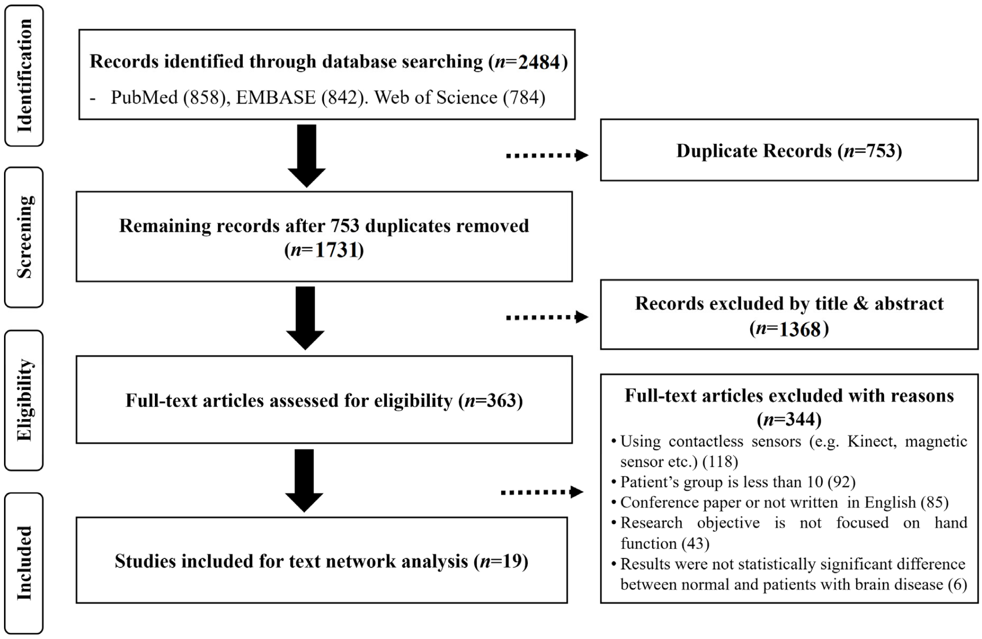


Figure 1. Flowchart of literatures selection process.

The inclusion process reviewed the full-text and removed the literatures that did not meet the criteria of study type, participant type, intervention type, measurement type, and outcome type, resulting in 19 works of literatures finally used for the study. The final 19 literatures selected in the inclusion process signified that they performed quantitative analysis of the hand function using sensors for patients with degenerative brain diseases, and the features of the included literatures are shown in Table 2.

Table 2. Features of Literatures included in this research.

Author (Year)	Subject Types (Participants *n*)	Sensor Types	Measurement Methods	Measurement Parameters
Dai et al. (2020) [13]	PD (n = 45)	IMU	Finger tapping	Number of tap or frequency; Maximum amplitude or angle
Graziola et al. (2020) [14]	TS, ADHD (n = 37)	Touch	Finger tapping	Interval; Number of tap or frequency; Tapping accuracy
Yang et al. (2019) [8]	Stroke (n = 11)	Force	Hand grip	Rising time; Maximum overshoot
Lai et al. (2019) [15]	Stroke (n = 22)	Force	Hand grip	Strength; Alternating time
Archer et al. (2018) [16]	Stroke (n = 15)	Force	Pinch strength	Strength; Error of target and observed force
Shima et al. (2018) [6]	PD (n = 30)	Magnetic	Finger tapping	Interval; Open and close velocity; Maximum amplitude or angle; Finger contact time

Table 2. *Cont.*

Author (Year)	Subject Types (Participants *n*)	Sensor Types	Measurement Methods	Measurement Parameters
Jovičić et al. (2018) [17]	PD, PSP-R, MSA-P (*n* = 42)	IMU	Finger tapping	Interval; Open and close velocity; Maximum amplitude or angle
Suzumura et al. (2018) [18]	AD, MCI (*n* = 46)	Touch	Finger tapping	Interval; Finger contact time; Time from sound signal to tap; Inter-hand phase difference
Lalvay et al. (2017) [4]	PD (*n* = 392)	Touch	Finger tapping	Finger contact time; Number of tap or frequency
Sano et al. (2016) [19]	PD (*n* = 31)	Magnetic	Finger tapping	Open and close velocity; Maximum amplitude or angle; Number of tap or frequency; Distance; Slope of maximum point
Schwartze et al. (2016) [20]	CL (*n* = 10)	Touch	Finger tapping	Interval; Time from sound signal to tap
Térémetz et al. (2015) [3]	Stroke (*n* = 10)	Force	Finger tapping	Number of tap or frequency; Error of target and observed force; Tapping accuracy; Release duration time
Kassavetis et al. (2015) [21]	PD (*n* = 14)	3-axis accelerometer	Finger tapping	Interval; Number of tap or frequency; Distance
Friedman et al. (2014) [11]	Stroke (*n* = 12)	Force	Finger tapping	Tapping accuracy
Stamatakis et al. (2013) [22]	PD (*n* = 36)	3-axis accelerometer	Finger tapping	Open and close acceleration; Number of tap or frequency; Number of hesitations and halt; Index for decrementing and augmenting; Index for decrementing angle
Lindberg et al. (2012) [23]	Stroke (*n* = 24)	Force	Hand grip	Strength; Error of target and observed force; Release duration time
Pradhan et al. (2010) [24]	PD (*n* = 30)	Force	Pinch strength	Error of target and observed force
Shima et al. (2009) [25]	PD (*n* = 33)	Magnetic	Finger tapping	Interval; Open and close velocity; Maximum amplitude or angle; Distance
van Roon et al. (2000) [26]	SH (*n* = 11)	Force	Finger tapping	Interval; Finger contact time; Strength

PD, Parkinson's disease; TS, Tourette syndrome; ADHD, Attention deficit hyperactivity disorder; PSP-R, Progressive supranuclear palsy–Richardson; MSA-P, Multiple system atrophy of parkinsonian type; AD, Alzheimer's disease; MCI, Mild cognitive impairment; CL, Cerebellar lesion; SH, Spastic hemiparesis.

2.4. Contents Design by Analysis of Text Network Using R

The data mining technique in the present study involved a text network that can extract a network of connections by analyzing the relationships between the keywords used in the literature and visualizing them. Through the network, the relationships between the keywords used in the literature were examined using frequency and individual attributes. This has the advantage of confirming the magnitude of the relative influence between the texts, which cannot be determined only through frequency, by processing or refining the text and recombining the keywords in the text. In general, through text network the average distance and centrality are determined to identify the characteristics of connected keywords, and centrality is the most frequently used. Centrality is an indicator to capture influence of the entire network centering on the main keywords. The present study used the degree centrality and betweenness centrality among several centralities. The degree centrality is the number of all edges connected to a keyword (node) in the network, and the higher the number, the more connections a keyword has. Equation (1) shows the calculation of degree centrality C_{d_i} in random node i [27].

$$C_{d_i} = \sum_{i=1}^{N-1} d_{ij} \qquad \begin{cases} i \neq j \\ i = 1, 2, \cdots, N \end{cases} \tag{1}$$

Here, d_{ij} is the number of edges where node i is connected to node j other than itself, and N refers to the total number of nodes in the network. The betweenness centrality indicates how much a node acts as an intermediary between other nodes within a network and refers to the extent to which one keyword plays a role in expanding the flow of meaning between the other keywords or controlling the network structure. Equation (2) shows the calculation of the betweenness centrality C_{b_i} for node i [28]. Here, g_{jk} indicates the number of shortest distance paths between node j and node k, and N denotes the total number of nodes in the network. $g_{jk}(i)$ indicates the number of cases where the shortest distance path between node j and node k passes through node i.

$$C_{b_i} = \sum_{j=1}^{N-1} \frac{g_{jk}(i)}{g_{jk}} \qquad \begin{cases} i \neq j < k \\ i = 1, 2, \cdots, N \end{cases} \tag{2}$$

Figure 2 visualizes the results of analyzing the degree and betweenness centralities of the brain disease symptoms of participants of each hand function measurement type in the 19 finally selected literature and the sensor types and parameters (The source code is available on GitHub https://github.com/hosang0815/Electronics, accessed on 4 January 2023). The main keywords were visualized as circles, and the relationship between the keywords as a line. The higher the degree centrality, the larger the size of the circle, and the higher the betweenness centrality, the thicker the line is. In other words, the larger the size of the circle, the greater the influence, and the thicker the line, the stronger the betweenness.

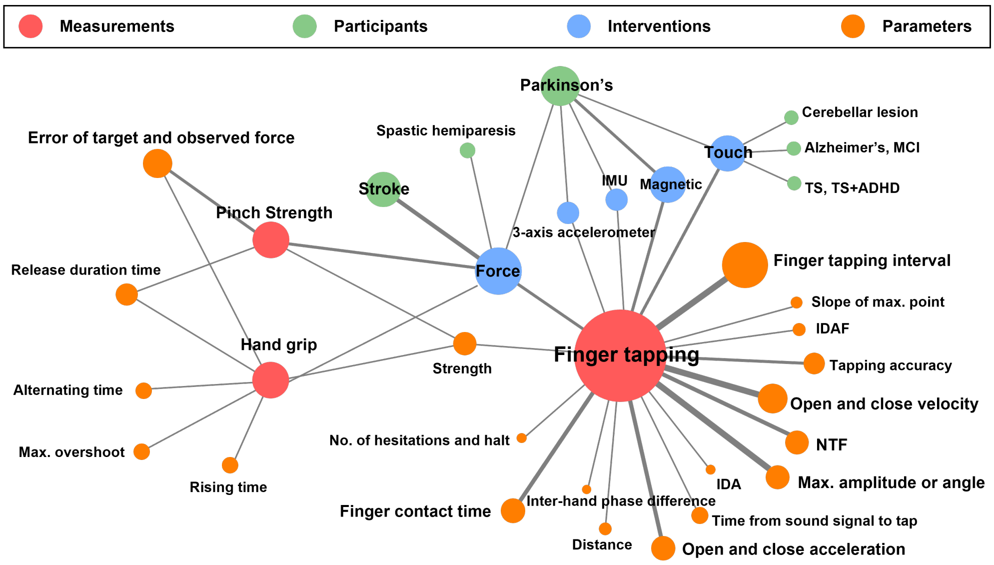


Figure 2. Visualization of degree and betweenness centralities for hand function measurement parameters. ADHD—Attention deficit hyperactivity disorder; IDAF—Index for decrementing and augmenting frequency; IDA—Index for decrementing angle; NTF—Number of taps or frequency; TS—Tourette syndrome.

The red circle in Figure 2 represents the types of hand function measurement and is divided into finger tapping, hand grip, and pinch strength. In particular, as the finger tapping circle is the largest, and the types of connected lines are diverse and thick for the finger tapping, it has the degree and betweenness centralities. The type of sensor is shown as the blue circle and is divided into 5 types: force, touch, magnetic, Inertial Measurement Unit (IMU), and 3-axis accelerometer. As force sensors have relatively high degree centrality compared to the other sensors and are linked to all types of hand function measurements, they can be used to quantitatively measure the hand functions of the stroke and Parkinson's patients among the brain disease patients. In Figure 2, the measurement parameters are shown as total 20 orange circles, and the degree centrality is high in the order of finger-tapping interval, open and close velocity, maximum amplitude or angle, finger contact time, open and close acceleration, and the number of tap or frequency. Here, it can be seen that the strength measurement parameter mediates all measurement types and analysis of various hand functions uses it.

Figure 3 shows a Sankey diagram of the flow between the keywords of sensors and parameters used in quantitative measurement methods for the hand function of each type of brain disease patient from 19 selected literatures. The color for each type is the same as in Figure 2, and keywords with higher degree centrality are expressed by thicker and darker lines. It shows that the Parkinson's and stroke accounted for a high proportion of participant types, with 9 and 6 cases. Furthermore, the sensor is connected to force in the case of stroke, and is connected to various other sensors in the case of Parkinson's. It means that there are more studies, conducted in various ways, to quantitatively measure the hand functions of Parkinson's patients than the stroke patients. Moreover, since the force sensor, the most used sensor, appears to be connected to all measurement types, it can be used to measure various hand functions quantitatively.

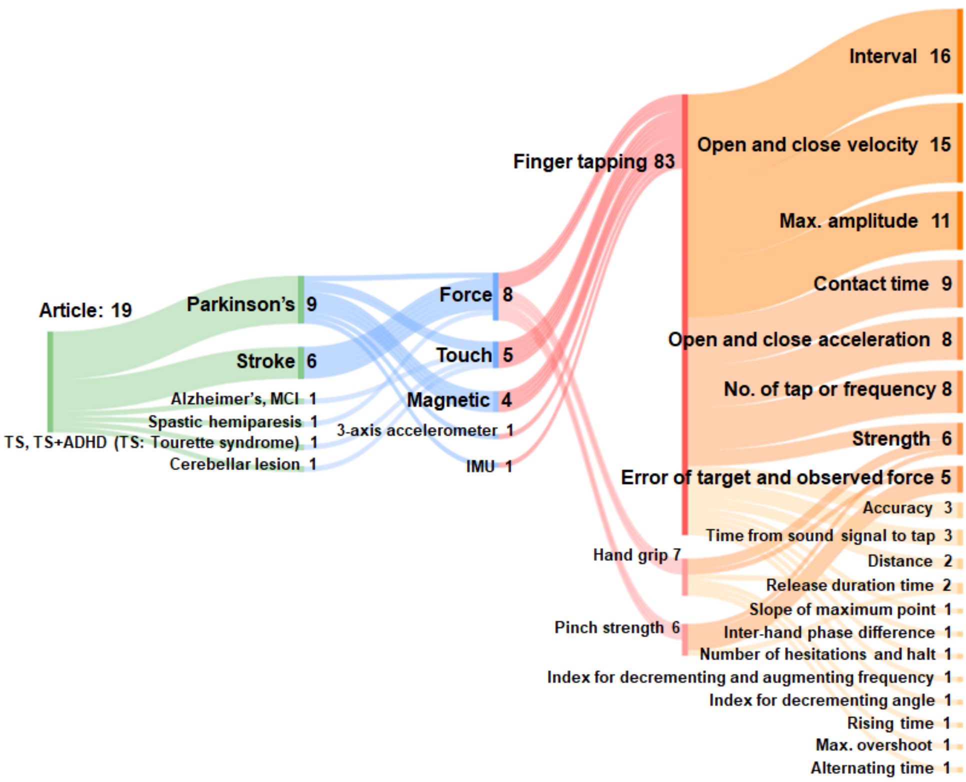


Figure 3. Sankey diagram of hand function measurement method for each type of brain disease patient.

Based on the above results, the participant, measurements, and sensor types were selected using the keywords with high degree and betweenness centralities in Figures 2 and 3. Devices that are capable of quantitatively measuring the hand functions of patients with degenerative brain diseases, such as Parkinson's disease and stroke, along with analytical software and contents were implemented. For the measurement type and the sensor to be used in the device, finger tapping and force sensors, respectively, with the highest degree and betweenness centralities, were selected, The measurement parameters with a high degree of centrality were also selected. Although the open and close velocity and open and close acceleration, which are measured with an acceleration sensor attached to a finger, show a high degree centrality among the measurement parameters, this study excluded them since it only uses the force sensor. Table 3 shows various measurement parameters using finger tapping and their explanations.

Table 3. Selected parameters to measure finger tapping.

Measurement Type	Measurement Parameters		Description
Finger tapping	1	Finger-tapping interval	Tapping interval time
		Finger contact time	Time at which contact occurs during tapping
		No. of taps or frequency	The number or frequency of tapping within a limited time
	2	Strength	The force of pressing the force sensor with the index finger
	3	Tapping accuracy	Accuracy of tapping in response to specific visual stimuli

First, "Finger-tapping interval", "Finger contact time" and "Number of taps or frequency" were measured through the interval and frequency between taps by letting the test subjects repeatedly tap the thumb and index finger as quickly as possible in a given time. These parameters can help identify patients with degenerative brain diseases since they have characteristics of slowed and deteriorated regularity of finger movement, resulting in irregular intervals between taps and contact time and a relatively small number of taps [29]. Second, the parameter "Strength" which indicates the force of tapping the finger, measures the weakened muscle strength of patients with degenerative brain diseases, thereby enabling analysis of the accelerated grip force and static and dynamic endurance of the fingers. Third, finger control ability was analyzed using "Tapping accuracy" which can measure the independence and accuracy of finger movements through tapping responses consistent with the presented visual information.

2.5. Pinch Gloves Using an FSR Sensor

A prototype of pinch gloves based on a Force Sensitive Resistor (FSR) sensor for finger-tapping measurement was designed and fabricated, as shown in Figure 4. To detect hand movements, a Bluetooth (FB155BC, Firmtech, Songnam, Republic of Korea) module was placed on the main board for wireless transmission and reception between the 9-axis Inertial Measurement Unit (IMU; MPU9250, InvenSense, San Jose, CA, USA) sensor and software (The block diagrams and circuit diagrams are available on GitHub). An Microcontroller Unit (MCU) on the main board was used to encapsulate the moving average data of the grip force of each finger received from the FSR sensor (FlexiForce A201-25, Tekscan, Norwood, MA, USA) and the finger movement acceleration data obtained from the IMU sensor into packets and wirelessly transmit and receive them.

The fabricated pinch gloves had 5 FSR sensors that can measure up to 11 kgf and are placed on each fingertip. As shown in Figure 4b, an acrylic concentrator (puck) was attached to the FSR sensor to concentrate the force applied to the sensor to reduce measurement errors and improve reproducibility. The concentrator used was manufactured with an 80% area (diameter: 7.5 mm) recommended by the sensor manufacturer for a diameter of 9.53 mm in the area detected by the sensor.

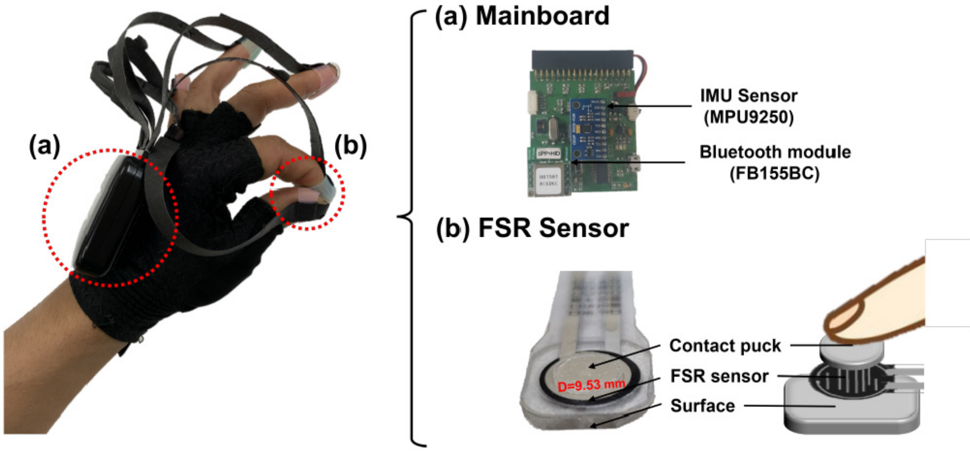


Figure 4. Prototype of the pinch gloves comprising FSR sensors.

2.6. Methods for Measurement Parameters of Hand Function

Table 3 summarizes the various parameters measured for finger tapping.

1. Finger-tapping interval
2. Finger contact time
3. Number of taps or frequency
4. Tapping strength
5. Tapping accuracy.

The "finger-tapping interval (FTI)" denotes the finger-tapping interval time. The *i*th finger-tapping interval time FTI_i is expressed as $FTI_i = FT_{i+1} - FT_i$. Here, FT refers to the finger-tapping time. Equation (3) shows the calculation of the coefficient of variation of finger-tapping interval time, CV_{FTI}, used as an indicator to evaluate aging and deterioration of body function. A higher value of the coefficient of variation value means a lower physical ability.

$$CV_{FTI} = \frac{FTI_{SD}}{FTI_{avg}} \tag{3}$$

Here, FTI_{SD} and FTI_{avg} represent the standard deviation and average of the total finger-tapping interval, respectively.

The "Finger contact time" refers to the time of finger contact, i.e., the time interval between the index finger and thumb touch and separate during tapping, as shown in Equation (2).

$$CT_{avg} = \frac{1}{N}\sum_{i=1}^{N} CT_i \tag{4}$$

Here, CT_i and CT_{avg} refer to *i*th and average finger contact time, respectively.

The "Number of taps or frequency" refers to the number and frequency of tapping in a given width (3 to 5 cm) and time (15 s) for tapping the index finger and thumb.

The "Tapping strength" denotes the pinching force using the index finger and thumb, and measures the strength applied to the FSR sensor and the duration of the applied finger force. Strength includes the maximum tapping strength, the average tapping when the strength is applied, and instantaneous acceleration force of strength (the time taken to reach the maximum strength from the time grip strength measurement begins) [30,31]. The duration of operation during which finger force is applied includes dynamic endurance. This indicates how long the strength can be maintained at the maximum grip and static endurance, maintaining a certain grip in an arbitrarily given period [32,33]. The definitions and formulas of various parameters for measuring this strength are as follows.

A. The maximum tapping strength from the measured strength values: S_{max}
$S_{max} = max(S_0, S_1, S_2, \cdots, S_{N-2}, S_{N-1})$, N is the measurement count.
B. Duration of operation of strength application: T_d
$T_d = (T_j - T_i)$, $(S_j = S_i = 0)$, $0 \leq i \leq j \leq N-1$, t_j and t_i refer to the start time and end time, respectively, when the grip strength value is "0", and the grip strengths at these times are S_i and S_j, respectively.
C. Average tapping strength during the period the strength is applied: S_{avg}
$S_{avg} = \frac{1}{N}(\sum_{i=1}^{N} S_i)$
D. Instantaneously accelerated strength (acceleration work) represents the relationship between the time from the strength measurement start time (T_i) to the time to reach the maximum strength (T_{max}) and the strength values obtained at this time (S_i, S_{max}): S_{acc}
$S_{acc} = \frac{S_{max} - S_i}{T_{max} - T_i}, i = 0$
E. Dynamic endurance time to maintain 90% or more of the maximum strength value: t_{max}
$t_{max} = t_q - t_p$, $t_p \leq t_{max} \leq t_q$, $S_p \leq S_{max}$, $0.9S_{max} \leq S_q$, S_p and S_q refer to the strength at t_p and t_q, respectively.
F. The rate of change of static endurance that maintains a certain strength for any given period: $S_{endurance}$
$S_{endurance}(\%) = \frac{S_{mean-lastsecond}}{S_{mean-firstsecond}} \times 100(\%)$, $S_{mean-lastsecond}$ refers to the average strength in the last second of the given period, and $S_{mean-firstsecond}$ refers to the average strength in the very first second.

The "Tapping accuracy" was implemented to measure the visual information's fast and accurate reaction time.

3. Results

The current study used the Unity 3D (ver. 2019.4.7.f1) game engine to implement the hand function measurement and analysis software and various applications for hand function improvement exercises.

3.1. Software for Strength Analysis of Finger Tapping

The tapping strength of patients with degenerative brain diseases is generally characterized by low endurance and poor speed due to decreased muscle strength, making these parameters useful for evaluation [34]. Endurance analysis was performed using finger-tapping strength and duration of operation, i.e., the maximum tapping strength, static endurance, and dynamic endurance, as shown in Figure 5. The finger-tapping strength was used for endurance by measuring the maximum force of pressing the force sensor with the index finger and thumb [35].

As shown in Figure 5a, the maximum tapping strength was measured by arbitrarily setting the measurement time and indicating the measurement start and end times with a beep sound. The blue and red dotted lines in section A show the time when the strength was applied (10% of the maximum strength) and the time when it was reached (90% of the maximum strength), respectively, which was used as an acceleration grip to evaluate the quickness of hand function.

Endurance can also be measured via dynamic and static endurance. The dynamic endurance measurement determines how long a user maintains a certain tapping strength above the red target line, as shown in Figure 5b. Here, the target line for maintaining a certain strength was 90% of the user's maximum tapping strength measured in advance. The static endurance in Figure 5c refers to maintaining the target line's strength and evaluating the amount of change in strength. Here, strength is presented as a weak strength (25–75% of the maximum), and the duration interval was set to 10 s to reduce muscle fatigue according to the American Industrial Hygiene Association (AIHA) measurement method [36].

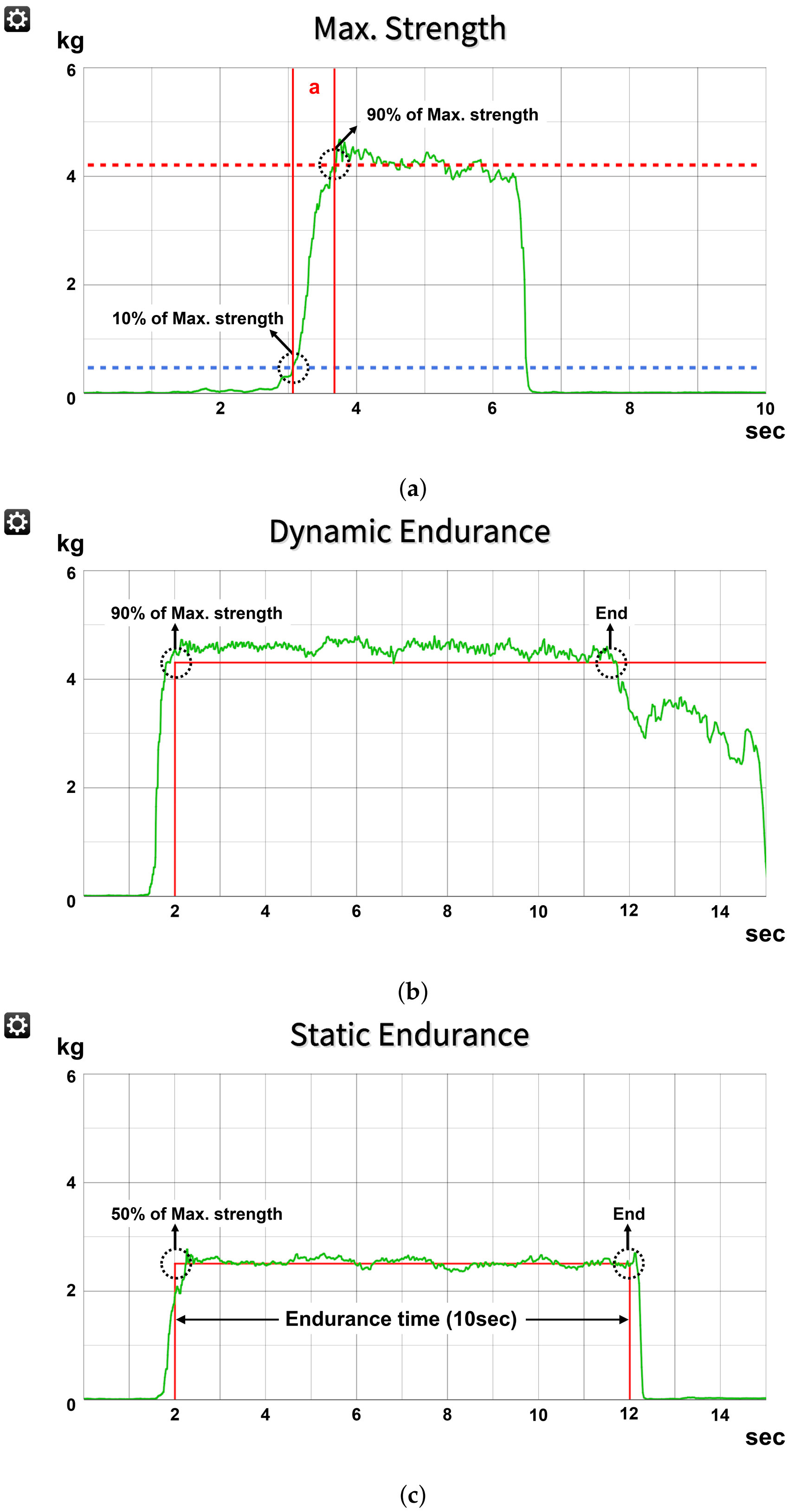
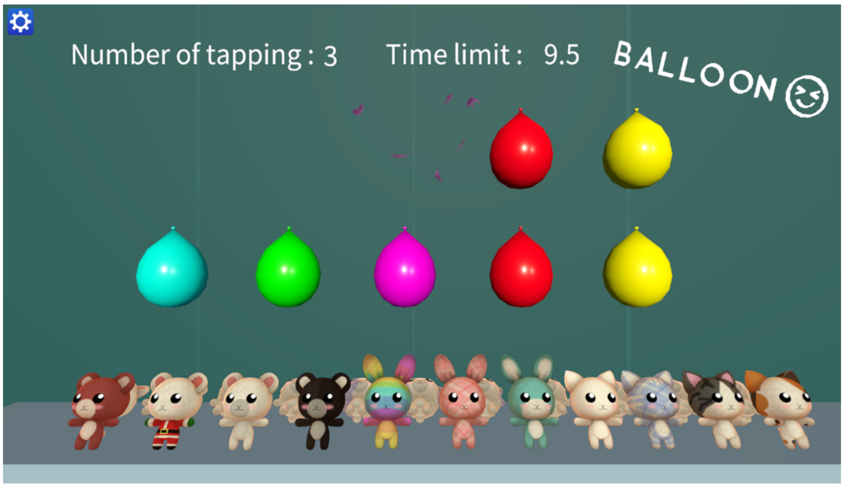


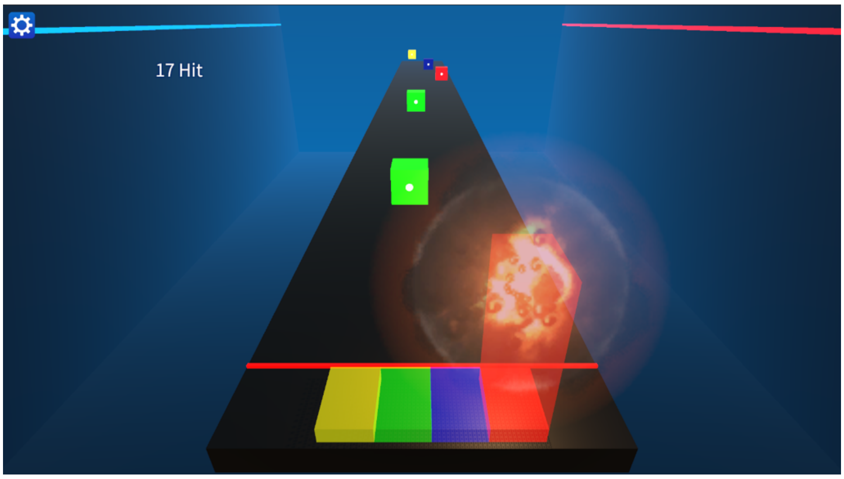
Figure 5. Software to analyze hand function endurance using the tapping strength and duration of operation. (**a**) Maximum tapping strength; (**b**) Dynamic endurance; (**c**) Static endurance.

3.2. Contents for Frequency and Accuracy Analysis of Finger Tapping

The number of taps or frequency and tapping accuracy were used to analyze the stability and accuracy of hand functions and measured using the content shown in Figure 6. To measure the number of finger tapping within a given time, as shown in Figure 6a, a balloon burst on the screen each time a tap was made. The time limit was set to 15 s to reduce measurement errors due to fatigue, and it was used to analyze the number of taps and coefficient of variation for intervals. Figure 6b shows the tapping accuracy of the rhythm game to measure how accurately finger tapping responded to the presented stimuli. The notes in this content dropped at 60 BPM, and the content determined whether finger tapping was performed whenever a note passed the red reference line in the lower part. The time taken for the note to cross the baseline was 0.3 s. The color of the note indicates the finger to be tapped. Yellow represents the index finger–thumb tapping, green represents the middle finger–thumb tapping, blue represents the ring finger–thumb tapping, and red represents the small finger–thumb tapping.



(**a**)



(**b**)

Figure 6. Contents to measure stability and accuracy of hand function using number of finger taps and presented stimuli. (**a**) Number of taps or frequency; (**b**) Tapping accuracy.

Since it is difficult to test the finger-tapping strength measurement software and contents mentioned above with real patients, it was measured and analyzed on ordinary people. The experiment measured 12 ordinary men and women in their 20 s (mean = 24 ± 2.8, male = 8, female = 4). The participants were recruited from computer engineering students at the Tech University of Korea, and they had introduced in detail to this study by the researchers. Written informed consent was obtained from each participant prior to participating in this study. Table 4 shows the results of the experiment conducted by the participants.

Table 4. Finger tapping results of 12 healthy men and women in their 20s.

Variables	Gender	
	Male (n = 8)	**Female (n = 4)**
Max. strength (kg)	4.1	2.6
Avg. strength (kg)	3.8	2.4
Dynamic endurance (s)	6.0	2.7
Static endurance (%)	3	4
Acceleration work (m/s^2)	6.0	5.1
No. of tap (×)	62.3	52.0
Frequency (Hz)	4.2	3.5
CV of interval (%)	14.0	12.9
Contact time (ms)	81.3	91.7
Accuracy (%)	94.7	96.5

We intended to verify whether comparison of the differences in hand function between ordinary men and women using the pinch gloves fabricated in this study can be used as a reference to study the same between the patients with degenerative brain diseases such as stroke and ordinary people. Figure 7 shows a radar chart through which the differences in hand function between men and women can be easily compared. The parameters with large differences in finger tapping between the two genders are shown in red, and they are mostly related to strength and endurance, such as maximum strength, average strength, and dynamic endurance, which showed larger values for the men than the women. Similarly, the men also showed higher values in acceleration work for quickness evaluation and number of taps and frequency for stability evaluation than the women. However, no significant difference between the men and women were observed for other parameters, such as static endurance, CV of interval, contact time, and accuracy.

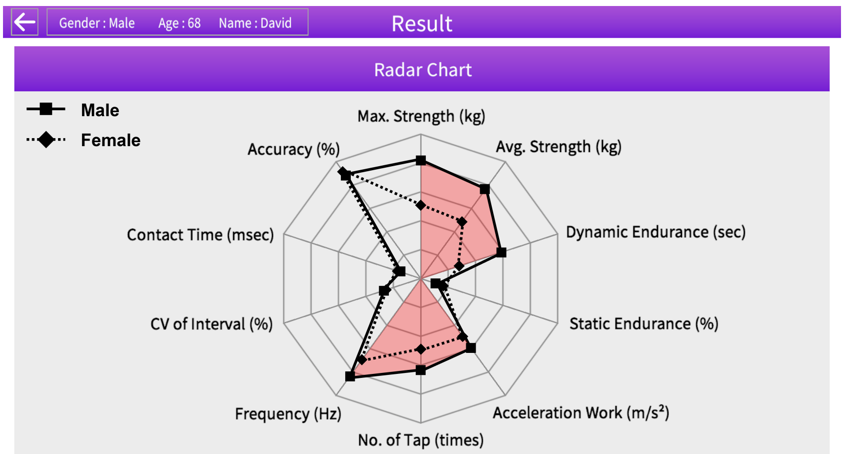
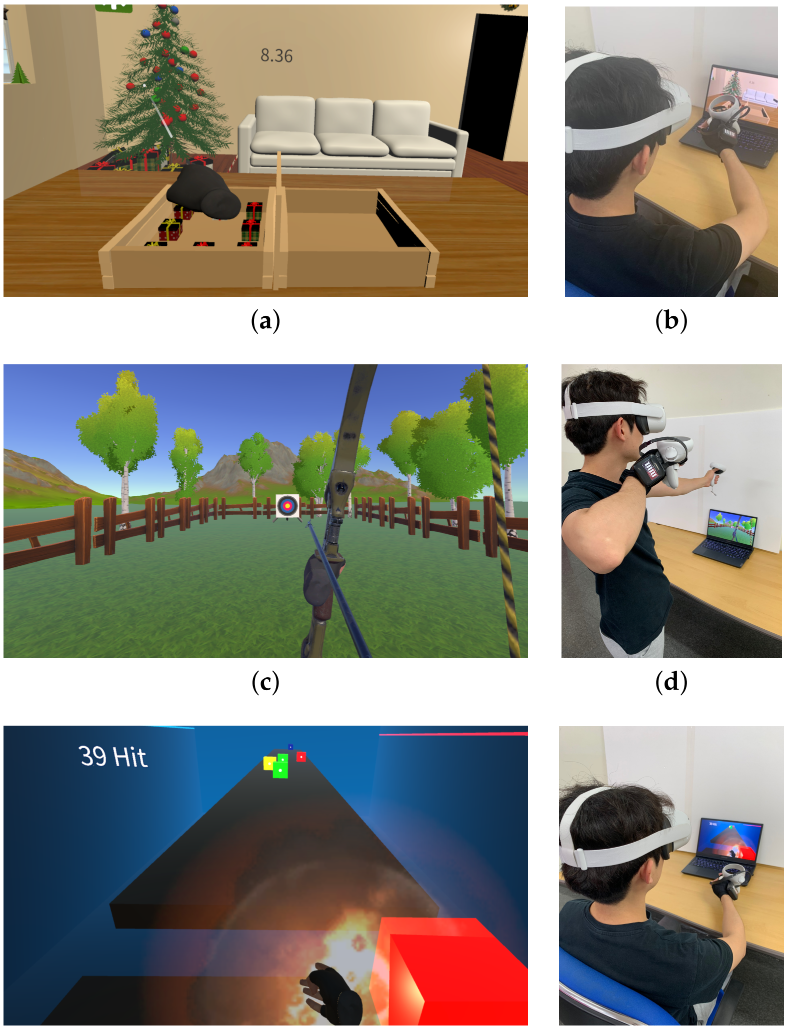


Figure 7. Radar Chart showing finger tapping data.

3.3. Serious Game Based on VR for Training Finger Tapping

Figure 8 shows the VR application contents implemented for hand function improvement training. The static endurance training consisted of a moving block game where the trainees picked up blocks in boxes placed on the right of the middle partition with their fingers and moved them to the left box within 1 minute. If a trainee maintained 50% of the premeasured maximum strength for 3 seconds, a block was considered picked up. This content was similar to the box and block test, which is an evaluation tool for observing simple hand function and coordination ability of people with reduced cognitive functions, such as attention and concentration, or limited hand function, and can be used for static endurance training and evaluating the degree of improvement in upper limb function. The dynamic endurance involved an arrow shooting game where a trainee shot an arrow at the target in standing position. It can be trained by having the trainee aim the bow at the target presented with the hand without the pinch glove and preventing the arrow from shooting with the hand wearing the glove until the strength reaches 90% of the measured maximum strength. The accuracy training was based on VR in the same way as the hand function accuracy measurement in Figure 6b, and the number and speed of falling notes can be adjusted.



(**a**) (**b**) (**c**) (**d**) (**e**) (**f**)

Figure 8. Training contents in virtual reality of a head-mounted display. (**a**) Moving block game for training static endurance; (**b**) the action of moving block game; (**c**) arrow shooting game for training dynamic endurance; (**d**) the action of arrow shooting game; (**e**) rhythm game for training accuracy; (**f**) the action of rhythm game.

4. Discussion

This study implemented tools, software, and contents for quantitatively measuring and analyzing hand functions in patients with degenerative brain diseases. First, the relevant literatures on the analysis of hand functions in patients with degenerative brain diseases were collected, and the frequency of use and influence of keywords were analyzed with a text network using keywords related to measurement tools, sensors, and analysis methods described in the literatures. The results showed that Parkinson's disease in the participant type, force sensor in the intervention type, and finger tapping in the measurement type had the highest degree centrality and betweenness centrality. A high degree centrality means that many studies focused on the analysis of hand functions in Parkinson's disease patients by finger tapping using force sensors. Moreover, a high betweenness centrality signifies that keywords are highly influential and crucial in analyzing the hand functions of patients with degenerative brain diseases.

The measurement parameters related to finger tapping showed a high degree of centrality in the order of finger-tapping interval, open and close velocity, maximum amplitude or angle, finger contact time, open and close acceleration, number of taps or frequency, and strength. However, among these parameters, the open and close velocity and open and close acceleration, which require an acceleration sensor to be attached to the finger, were excluded. In particular, it was confirmed that strength was used in analyzing various hand functions since it is linked to all the measurement types. Based on these results, we selected the finger tapping and force sensor as the measurement type and the sensor, respectively, using the keywords with a high degree centrality and betweenness centrality and designed devices and content that can quantitatively measure hand function in patients with Parkinson's disease and stroke, and perform rehabilitation exercises.

The software comprised maximum tapping strength, static endurance, dynamic endurance, and acceleration work that can evaluate endurance and quickness by measuring the finger-tapping strength and operation time using the index finger and thumb. Furthermore, the contents consisted of the number of taps or frequency to evaluate the stability of hand functions by measuring the repeat count of finger tapping within a given time (15 s). The coefficient of variation of the tapping interval and the average contact time and the tapping accuracy were obtained to evaluate the accuracy of hand functions from the response time to the visual stimuli. Moreover, training contents to improve endurance and accuracy were implemented based on VR to increase the level of immersion among trainees and induce active participation in training.

Based on the above results, 12 ordinary subjects (8 men and 4 women) were tested using the pinch gloves to verify the implemented software and contents by comparing the hand functions of the men and women using the parameters proposed in this study. The finger tapping results showed that the men displayed a higher value than women in maximum strength and average strength of muscle strength, acceleration work of quickness, number of taps and frequency of stability, and dynamic endurance. Considering that the test subjects were healthy ordinary people, it is similar to the results of other studies showing that men had higher muscle strength and quickness than women [37–39]. On the other hand, no differences between the men and women were observed in static endurance that keeps low-intensity forces constant, CV of interval and contact time for stability evaluation of keeping finger tapping constant, and accuracy of response to presented visual stimuli. This was because they did not require muscle strength and quickness. The experiment verified the software and contents implemented in ordinary subjects, but it is necessary to compare not only the ordinary people but also various experimental control groups through quantitative measurement and analysis of hand function. In other words, the experiments in this study require special note in interpretation because the subjects were relatively young and healthy, and various studies on people of a wider age range and disease are needed for verification and generalization.

In this study, we used only parameters that can analyze hand function with finger tapping using an FSR sensor based on the frequently used keywords through text network analysis of various publications that meet the research goals related to hand function. However, more effective research results can be obtained if quantitative measurements and various analyses are carried out using additional sensors such as magnetic and IMU, which are relatively infrequently used.

5. Conclusions

We collected 2484 literatures for text network analysis and then excluded those that were related to the effects of improving upper limb function with drug medication and the lower limb functions using keywords such as foot and gait. Eventually, 19 literatures that met the research objective of this study were selected. This study obtained text network analysis results from selected literatures by using keywords of Parkinson's disease as the participant type, force sensor as the intervention type, and finger tapping as the measurement type. Moreover, we implemented the software and contents to measure and analyze various parameters related to finger tapping to use pinch gloves utilizing the FSR force sensor. The software consisted of maximum tapping strength, static endurance, dynamic endurance, and acceleration work that can evaluate endurance and quickness by measuring finger-tapping strength and operation time using the index finger and thumb. Furthermore, the contents consisted of the number of taps or frequency to evaluate the stability of hand functions by measuring the repeat count of finger tapping within the given time (15 s) and then analyzing the coefficient of variation of the tapping interval and the average contact time and the tapping accuracy to evaluate the accuracy of hand functions by analyzing the response time to the visual stimuli. Moreover, the training contents to improve endurance and accuracy were implemented based on VR to increase the level of immersion among trainees and induce active participation in training.

In conclusion, this study reports the results of collecting studies of many researchers on hand function measurement methods and analysis of people with degenerative brain disease, analyzing which parameters were the most common and frequently measured. Therefore, if researchers share measurement parameters for hand function research, it will help to quantitatively compare results and derive objective research results.

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