Archives of Physical Medicine and Rehabilitation

journal homepage: www.archives-pmr.org

Archives of Physical Medicine and Rehabilitation 2023;000: 1−10

ORIGINAL RESEARCH

Effectiveness of a Telerehabilitation Evidence-Based Tablet App for Rehabilitation in Traumatic Bone and Soft Tissue Injuries of the Hand, Wrist, and Fingers

Alejandro Suero-Pineda, PT, MSci,[a] Ángel Oliva-Pascual-Vaca, PT, PhD,[a] Manuel Rodríguez-Piñero Durán, MD, PhD,[b] Pablo Rodríguez Sánchez-Laulhé, PT, MSci,[a] María Ángeles García-Frasquet, MD, PhD,[c] Jesús Blanquero, PT, PhD[a]

From the [a]Physiotherapy Department, Faculty of Nursing, Physiotherapy and Podiatry, University of Sevilla, Seville, Spain; [b]Service of Physical Medicine and Rehabilitation, Hospital Universitario Virgen Macarena, Seville, Spain; and [c]Hand Surgery Division, Virgen Macarena University Hospital, Seville, Spain.

Abstract

Objective: To assess whether feedback-guided exercises performed on a tablet touchscreen improve clinical recovery and reduce health care usage more than the conventional home exercise program prescribed on paper in patients with bone and soft tissue injuries of the wrist, hand, and/or fingers treated by public health services.

Design: A multicenter assessor-blinded, parallel, 2-group controlled trial.

Setting: Trauma and rehabilitation services of 4 hospitals.

Participants: Six hundred sixty-three patients with limited functional ability due to bone and soft tissue injuries of the wrist, hand, and/or fingers (N=663).

Interventions: The experimental group received a home exercise program using a tablet-based application with feedback, monitoring, and progression; the control group received an evidence-based home exercise program on paper.

Main Outcome Measures: The primary outcome was functional ability through Patient Rated Wrist Evaluation for wrist conditions and the short version of Disabilities of the Arm, Shoulder and Hand for all other hand pathologies. Secondary outcomes included dexterity, pain intensity, grip strength, and health care usage (number of patients referred to rehabilitation service and number of clinical appointments).

Results: The experimental group showed a significant improvement on the Patient Rated Wrist Evaluation (P=.001) and the short version of Disabilities of the Arm, Shoulder and Hand (P=.001) with medium effect sizes (η^2=0.066-0.067) when compared with the control group. Regarding health care usage, the experimental group presented a reduction of 41% in the rate of referrals to face-to-face rehabilitation service consultations, a reduction of rehabilitation consultations (mean difference=−1.64; 95% confidence interval, −2.64 to −0.65) and physiotherapy sessions (mean difference=−8.52, 95% confidence interval, −16.92 to −0.65) compared to the control group.

This study was supported by the Innovation Projects Grant #0143-2017 of the Health Council of Andalusian Government. This study is part of an activity that has received funding from the European Institute of Innovation and Technology (EIT). This body of the European Union receives support from the European Union's Horizon 2020 research and innovation program. The funding body did not participate in the design of the study or in the collection, analysis, and interpretation of the data or in the writing of the manuscript.

Clinical trial registration number: NCT04669704.

Disclosures: Andalusian Health Service has a collaboration agreement concerning the ReHand solution and may benefit financially if this research generates a successful marketing value related to ReHand. The terms of this agreement have been reviewed and approved by Andalusian Health Service in accordance with its policy on Financial Conflict of Interest. Alejandro Suero and Jesús Blanquero were the initiators of the project and founded a spinoff.

https://doi.org/10.1016/j.apmr.2023.01.016

Conclusions: In patients with bone and soft tissue injuries of the wrist, hand, and/or fingers, prescribing feedback-guided exercises performed on a tablet touchscreen was more effective for improving patients' functional ability and reduced the number of patients referred to rehabilitation consultation and number of clinical appointments.

Archives of Physical Medicine and Rehabilitation 2023;000:1−10

Hand, wrist, and finger injuries incidence and costs[1] have increased during the last 10 years and thus the efforts to improve their approach.[2] These pathologies represent between 10% and 30% of all emergency department presentations and 28% of all musculoskeletal injuries.[1] Colen et al found an increase in direct cost of 18.8% between 2009 to 2012 from $40.9 billion to $48.6 billion in US emergency departments.[3] In addition, the indirect costs for patients, companies, and health care systems are remarkable because they commonly involve therapy rehabilitation procedures, a restriction in work, self-care, and leisure during an individual's economically productive years.[1,2] Because of this great economic burden on society, hand injuries rank as the most expensive injury types: 32% more than lower limb fractures, 39% more than hip fractures, and 108% more than skull/brain injury.[4]

Exercise therapy is a key part of treatment of these pathologies. Exercise programs are widely supported by current evidence for rehabilitation of common hand, wrist, and finger injuries like wrist fracture,[5] carpal tunnel release,[6] hand/finger fractures,[7] thumb base surgery,[8] Dupuytren surgery,[9] or tendon surgery.[10-12]

Telerehabilitation is "the delivery of rehabilitation services at a distance via telecommunication technology such as phone, videoconferencing and the internet."(p143).[13] The development of mHealth or mobile health allows the implementation of devices, such as smartphones or tablet devices, as accessible and easy-to-use tools in health care.[14-16] In the rehabilitation process, provision of remote rehabilitation services (telerehabilitation) in conjunction with the ability to monitor clinical evolution and treatment adherence (tele-monitoring) seems promising.[13]

The efficacy of telerehabilitation after upper limb interventions (eg, carpal tunnel release surgery, rotator cuff tear, proximal humerus fractures)[17-19] and total arthroplasty (eg, shoulder, knee, hip)[18,20-22] has been assessed. Evidence shows that outcomes commonly considered in postsurgical physical therapy, like strength or functional activities and disability, are similar or even superior to those of face-to-face sessions.[18-22] Thus, telerehabilitation has been proposed to improve patient care and the sustainability of health care services, reducing the number of face-to-face sessions, waiting lists, and patient transportation and resulting in early discharging from rehabilitation service.[23,24]

A systematic review highlighted that telerehabilitation for musculoskeletal conditions in addition to usual care is more favorable than usual care alone for the improvement of physical function and pain. Also, telerehabilitation treatment is implemented alone is equivalent to face-to-face sessions for the improvement of physical function.[25]

The coronavirus disease 2019 pandemic forced rehabilitation units to stop face-to-face activity because rehabilitation services were considered nonessential. This situation eliminated barriers and forced the adoption of telerehabilitation by patients and clinicians, which may contribute to testing its benefits and larger-scale adoption.[26,27]

List of abbreviations:

ANCOVA	**analysis of covariance**
CI	**confidence interval**
DASH	**Disabilities of the Arm, Shoulder and Hand**
MCID	**minimal clinically important difference**
NHPT	**Nine-Hole Peg Test**
PRWE	**Patient Rated Wrist Evaluation**
QuickDASH	**short version of Disabilities of the Arm, Shoulder and Hand**
VAS	**visual analog scale **

Method

Design

A multicenter, controlled, parallel group, single-blind clinical trial was conducted in the orthopedic surgery and rehabilitation services of 4 hospitals. This clinical trial was registered in ClinicalTrials.gov (ID NCT04669704). The hospitals' ethics committees approved this study.

Procedure

Participants were selected by services participating in this study. During the first follow-up after surgery or splint removal with an orthopedic consultant, baseline evaluation was assessed and patients were allocated to 1 of the 2 study groups. At this point, the participants were instructed to start the treatment corresponding to their group. Both groups received the same usual care from the services: periodic 4-week trauma and orthopedic surgery service follow-up consultations during which it was decided whether patients needed to be referred to the rehabilitation service. Patients referred to the rehabilitation service had a face-to-face consultation with a physiatrist and were considered for face-to-face physiotherapy sessions. A blinded evaluator assessed clinical variables at baseline before group allocation and 4 weeks and 3 months after the allocation.

Participants

Patients aged 18+ years with traumatic bone and soft injuries of the hand, wrist, and/or fingers were selected (table 1). Two experienced physiotherapists screened all patients and excluded individuals with any history of neurologic pathology that affects the upper limb, with psychiatric illness, or those who were noncooperative.

Intervention

Both experimental and control groups received a home exercise program with a duration of 20-25 minutes. A researcher made

Table 1 List and frequency of pathologies included in the study

Pathology	Experimental (n=240), n (%)	Control (n=352), n (%)	*P* Value
Carpal tunnel release	82 (34.2)	108 (30.7)	.29
Distal radius fracture (surgical)	56 (23.3)	69 (19.6)	
Distal radius fracture (conservative)	27 (11.2)	51 (14.5)	
Osteoarthritis of the thumb (surgical)	22 (9.2)	20 (5.7)	
Dupuytren (surgical)	9 (3.8)	29 (8.2)	
Metacarpal fractures (surgical)	6 (2.5)	11 (3.1)	
Metacarpal fractures (conservative)	5 (2.1)	16 (4.5)	
Scaphoid fracture (surgical)	5 (2.1)	10 (2.8)	
Carpal instability (surgical)	5 (2.1)	3 (0.9)	
Total wrist arthrodesis	4 (1.7)	3 (0.9)	
Trigger finger (surgical)	4 (1.7)	4 (1.1)	
Fractures of the radius and ulna (surgical)	4 (1.7)	5 (1.4)	
Fractures of the radius and ulna (conservative)	3 (1.2)	3 (0.9)	
Scaphoid fracture (conservative)	2 (0.8)	8 (2.3)	
Cubital tunnel release	2 (0.8)	1 (0.3)	
Swan neck deformity (surgical)	1 (0.4)	1 (0.3)	
Open wounds of the forearm, hand, and/or finger(s)	1 (0.4)	1 (0.3)	
Enchondromas	1 (0.4)	1 (0.3)	
De Quervain	1 (0.4)	0	
Fractures of 1 or more phalanges of the hand	0	3 (0.9)	
Triangular fibrocartilage complex injury (surgical)	0	3 (0.9)	
Dislocations of finger(s)	0	1 (0.3)	
Injury of the ulnar collateral ligament of thumb	0	1 (0.3)	

weekly follow-up phone calls to participants in both groups to promote adherence and to solve any doubts participants had.

Experimental group

In the experimental group, participants received the ReHand tablet app as a home-based form of telerehabilitation. ReHand is a software with a tablet application (Android and iOS) that has a battery of specific feedback-guided exercises for recovery after traumatic bone and soft tissue injuries affecting the hand, wrist, and/or fingers to be performed using a touchscreen. The exercise program was individualized according to pathology. An example exercise is the pinch exercise with the index finger, performing a controlled movement in a painless range guided by feedback during 25 seconds (fig 1).

Control group

In the control group, participants received a home exercise program on paper conventionally used by the services participating in the study. The exercises are focused on the mobility of the entire upper limb, with exercises relating to the wrist and hand having greater relevance. An example exercise is to touch each finger pad to the thumb pad 15 times. These exercises are listed in table 2.

Allocation

The assignment to each group was made nonrandomly, depending on whether or not the participant had access to a tablet device. Because the health care system did not plan to include a tablet delivery and return service for patients, the study was planned accordingly to this reality of the clinical practice. Thus, participants who had access to a tablet device were assigned to the experimental group and all other participants were assigned to the control group.

Outcomes

The outcome assessor who collected the data was blinded to participant allocations.

Primary outcome

Patient functional ability through patient-reported measures of disability and pain are widely used as primary outcomes research.[28] We use the Patient Rated Wrist Evaluation (PRWE) for wrist conditions and the short version of Disabilities of the Arm, Shoulder and Hand (QuickDASH) for all other hand pathologies.

The Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire is the most commonly used questionnaire in hand surgery and has the most published research assessing structural validity.[29] It has been shown to be a highly reliable, internally consistent, and valid tool assessing disabilities of the hand.[30-32] The final score is between 0 and 100, with higher scores indicating more disability.

The PRWE is a joint-specific outcome measure that is widely used and recommended in evaluating patients with wrist diseases or injuries. The test-retest reliability of the PRWE is excellent and its Spanish version has been validated.[28,33] The final score is between 0 and 100 points, with higher scores indicating more disability.

Secondary outcome—Clinical

Handgrip strength was assessed using a hydraulic hand dynamometer (200 lb Baseline hydraulic hand dynamometer[a]) following the guidelines of the American Society of Hand Therapy.[34] Self-reported pain was assessed using a visual analog scale (VAS). Participants were told to report their pain intensity using the 0 to 10 VAS, where 0 is *no pain* and 10 is *the worst imaginable pain*. The VAS has good test-retest reliability[35] and is able to detect

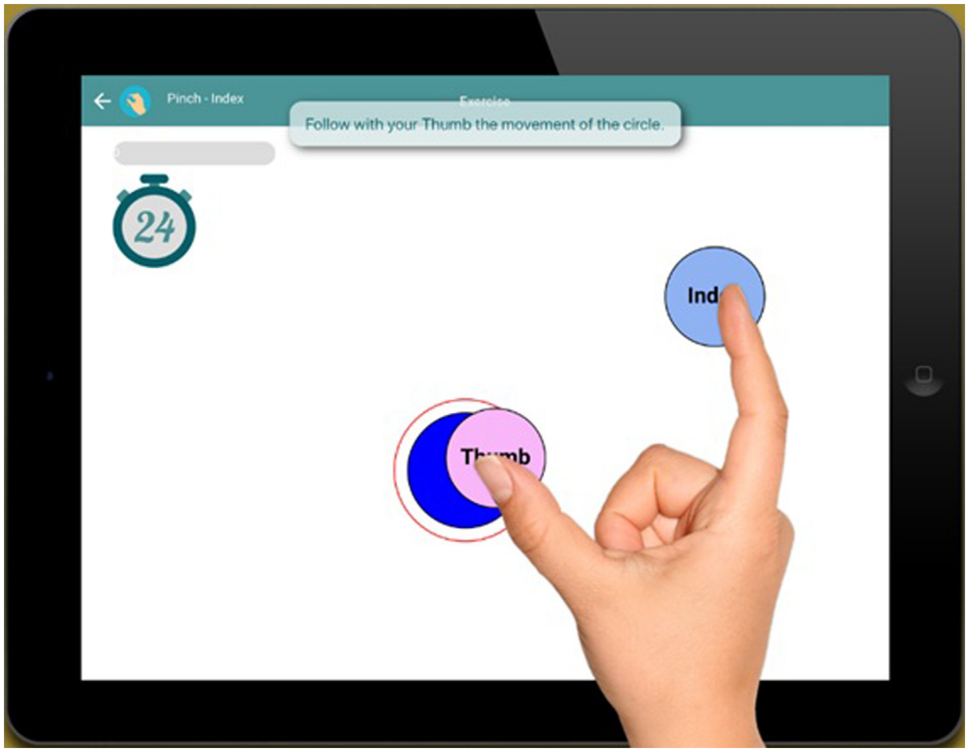

Fig 1 Pinch exercise performance (experimental group).

clinically relevant effects after intervention in people with different hand disorders.[36] Dexterity was assessed using the Nine-Hole Peg Test (NHPT).[37]

Secondary outcome—Health care usage

In respect to health care system usage, referrals to rehabilitation service (ie, the number of patients referred) and face-to-face consultations (ie, the number of rehabilitation consultations and physiotherapy sessions) were tallied from the hospital data management system by professionals blinded to patient allocation. Economic savings were estimated according to health care usage.

Data analysis

For wrist fracture cases, sample size estimation was based on detecting a mean between-group difference (experimental vs control) in changes across the assessment points (baseline vs 3 months) higher than 11.5 points for the overall PRWE, established as the clinically relevant threshold for this clinical questionnaire.[9] Assuming a 2-tailed hypothesis, an alpha value of .05, a desired power of 80%, and a 40% dropout rate, 148 participants were needed per group to complete the study. For all other pathologies, sample size estimation was based on detecting a mean between-group difference (experimental vs control) in changes across the assessment points (baseline vs 1 month and baseline vs 3 months) higher than 6.8 points for the overall QuickDASH, established as the clinically relevant threshold for this questionnaire.[11] Assuming a 2-tailed hypothesis, an alpha value of .05, a desired power of 80%, and a 40% dropout rate, 182 participants were needed per group to complete the study. It is the software used for the sample size estimation.[b]

To detect a difference equal or superior to the main outcomes minimal clinically important difference (MCID), a total of 660 patients were needed according to the previous sample calculation.

Table 2 Description of control intervention conventionally used in the Andalusian Public Health Services

Exercise	Sets	Repetitions
1. Make a fist and then extend the fingers.	3	15
2. With the hand opened and fingers extended, maximally extend the wrist.	3	15
3. With the hand opened and fingers extended, maximally abduct the fingers.		
4. Contact each finger's pad with the thumb pad.	3	15
5. With a (semi-) closed fist, flex and extend the wrist.	3	15
6. With the hand opened and fingers extended, deviate the hand toward the radius and ulna.	3	15
7. With a semi-closed fist, perform rotating movements of the fist.	3	15
8. Standing or sitting in a chair, extend the elbow so that the upper limb hangs beside the body.	3	10
9. From the previous position, slowly raise the upper limb to the horizontal plane with the elbow in extension.	3	10
10. From the previous position, flex the elbow and touch the same shoulder with your fingers.	3	10

NOTE. All exercises must be performed for 15 repetitions in 3 sets.

Analyses were performed using SPSS.[c] For health care usage outcomes, mean between-group differences (95% confidence intervals [CIs]) are reported. For baseline characteristics, Student *t* tests or Mann-Whitney *U* tests for continuous variables (depending on normality) and chi-square tests for categorical variables were used for between-group comparisons. An analysis of covariance (ANCOVA) of the clinical outcomes with the baseline as covariate was performed to compare the effects of each intervention on measured outcomes. The between-group factor was the treatment group (experimental vs control group), the within-group factor was the time of assessment (baseline, 1 month, and 3 months) and the covariates were the baseline scores. The small, medium, and large η^2 effect sizes were 0.01, 0.059, and 0.138, respectively. P <.05 was considered to be statistically significant.

Results

Participants

Seven hundred eighteen patients were screened and 663 met the inclusion criteria; 592 completed the study's health care usage outcome measurement and 425 completed the minimum follow-up needed to evaluate MCID in main outcomes. One hundred ninety-five patients were allocated to the experimental group and 230 to the control group. The flow of participants through the remainder of the study is presented in figure 2. The demographic and baseline clinical outcomes measures did not differ significantly across the treatment groups and are presented in table 3.

Effect of intervention on the primary outcome

Adjusting for baseline outcomes, the mixed-model ANCOVA revealed a significant Group × Time interaction for the primary outcome in the QuickDASH ($F_{1.88,425}$=8.966, P<.001, η^2=0.038) and in the PRWE ($F_{1.838,352}$=10.247, P<.001, η^2=0.051). The confidence interval indicated that the true effect of the intervention was beneficial for patients in the experimental group according to the QuickDASH at 1 and 3 months and according to the PRWE at 3 months (table 4). Between-group effect sizes were medium for both the QuickDASH ($F_{1,226}$=16.168, P<.001, η^2=0.067) and PRWE ($F_{1,192}$=13.531, P<.001, η^2=0.066) table 5).

Effect of intervention on secondary clinical outcomes

Between-group differences were significant in all second clinical outcomes but with a small effect size: handgrip strength ($F_{1,346}$=4.119, P=.043, η^2=0.012), pain ($F_{1,399}$=15.585, P<.001, η^2=0.038), and dexterity ($F_{1,346}$=20.448, P<.001, η^2=0.056; tables 4 and 5).

A subgroup analysis of patients who were referred and received face-to-face physiotherapy sessions, those who were referred and not given face-to-face physiotherapy sessions, and those who were not referred for rehabilitation was conducted for

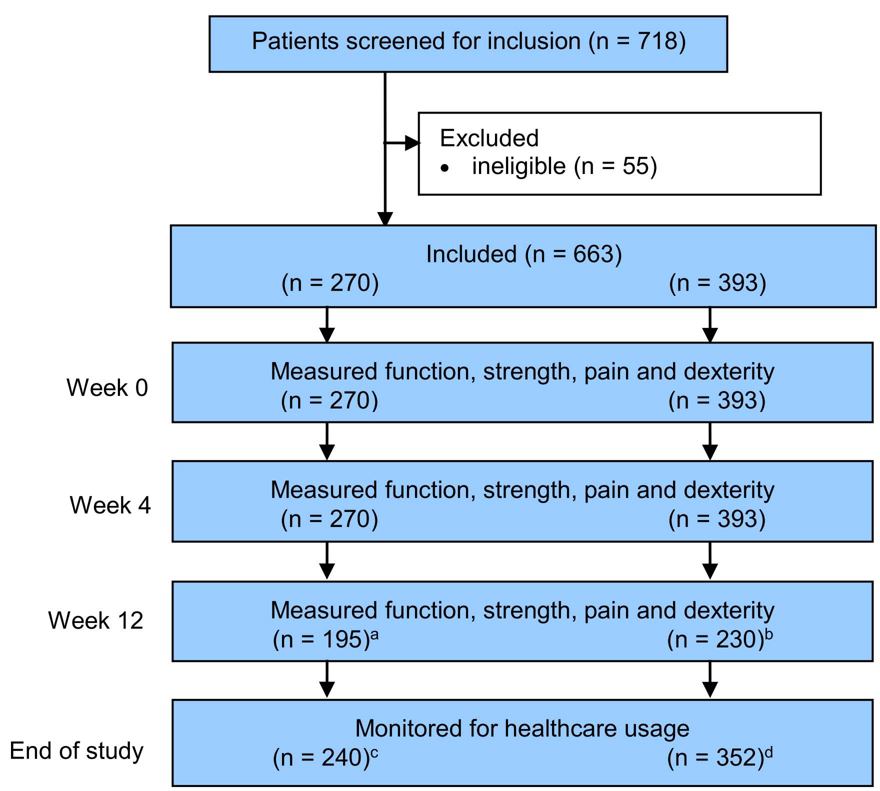

Fig 2 Design and flow of participants through the trial. *Seventy-five participants were unavailable for clinical measurements after discharge. †One hundred sixty-three participants were unavailable for clinical measurements after discharge. ‡Health care usage data for 30 patients could not be tallied from the hospital data management system. §Health care usage data for 40 patients could not be tallied from the hospital data management system.

Table 3 Demographic characteristics and mean±SD of baseline clinical outcomes

	Experimental (n=195)	Control (n=230)	*P* Value
Age, y	51 (11.64)	52 (12.19)	.15
Sex, n (%)			
Female	133 (68)	152 (66)	.68
Male	62 (32)	78 (34)	
Pathologies			.83
Wrist fractures	85	98	
Soft tissue injuries and hand fractures	110	132	
QuickDASH (0 to 100)	70 (19)	68 (20)	.17
PRWE (0 to 100)	73 (19)	75 (17)	.18
Grip strength (kg)	15 (14)	16 (14)	.25
Pain (0 to 10)	5.5 (2.5)	5.7 (2.7)	.22
Nine-Hole Peg Test (s)	30 (19)	31 (22)	.4

Table 4 Mean (95% CI) difference between groups for the clinical outcomes

Outcome	Between-Group Difference	
	Week 4−Week 0 Exp Minus C	Week 12−Week 0 Exp Minus C
QuickDASH	−8.83 (−13.7 to −3.95)	−11.12 (−17.29 to −4.96)
PRWE	−6.45 (−11.59 to −1.3)	−13.31 (−19.99 to −6.63)
NHPT	−2.35 (−3.44 to −1.25)	−2.89 (−2.89 to −1)
Grip	1.54 (−0.78 to 3.86)	3.75 (0.47-7.03)
Pain	−0.7 (−1.13 to −0.27)	−0.95 (−1.48 to −0.42)

Abbreviations: C, control; Exp, experimental

both the primary and secondary clinical outcomes and the results are presented in the supplementary material (available online only at http://www.archives-pmr.org/).

Effect of intervention on secondary outcomes health care usage

There was a significant difference in referrals to rehabilitation service between the control group and the experimental group (*P*<.001). The experimental group showed a reduction in the number of patients referred to the rehabilitation service (29%, 69/240) compared to the control group (48%, 170/352). Adjusting the percentage of referrals, the experimental group presented a reduction of 41% in the rate of referrals to face-to-face rehabilitation service consultations.

Of the 239 patients referred to rehabilitation service, 117 received face-to-face consultations based on physiotherapy sessions and follow-up rehabilitation consultations. Patients in the experimental group showed a reduction in the average number of clinical appointments with a rehabilitation consultant (by about 2 visits, *P*<.001) and a physiotherapist (by about 9 visits, *P*=.02). The confidence intervals around these effect estimates confirmed the benefit (table 6).

Table 5 ANCOVA results for each group clinical outcomes

	Pretreatment, Mean±SD		Posttreatment 1 Month, Mean±SD		Posttreatment 3 Month, Mean±SD		ANCOVA		
Outcome	Exp Group (n=195)	C Group (n=230)	Exp Group (n=195)	C Group (n=230)	Exp Group (n=195)	C Group (n=230)	F	*P*	η^2
QuickDASH	70.51 (19.29)	68.05 (19.55)	42.01 (21.61)	49.10 (24.71)	26.50 (25.25)	36.01 (26.69)	16.16	.001	0.067
PRWE	72.81 (18.58)	75.18 (17.28)	48.69 (23.89)	57.37 (22.91)	28.97 (22.94)	43.89 (28.27)	13.53	.001	0.066
NHPT	30.43 (19.04)	30.69 (22.08)	20.16 (4.12)	21.78 (7.72)	19.09 (4.35)	20.69 (5.25)	20.45	.001	0.056
Grip	15.38 (14.12)	16.33 (14.58)	27.66 (16.86)	27.29 (18.31)	37.89 (20.69)	35.91 (20.25)	4.12	.043	0.012
Pain	5.51 (2.5)	5.71 (2.78)	4.32 (2.49)	5.09 (2.39)	2.91 (2.74)	3.94 (2.98)	15.58	.001	0.038

Abbreviations: C, control; Exp, experimental.

Table 6 Mean±SD for each group and mean between-group difference (95% CI) for health care usage

Outcome	Exp (n=38)	Con (n=79)	Between-Group Difference (95% CI) Exp−Con
Physiotherapy session (n), mean±SD	25.53 (16.49)	34.05 (29.24)	−8.52 (−16.92 to −0.65)
Rehabilitation consultations (n), mean±SD	3.22 (1.77)	4.86 (3.35)	−1.64 (−2.64 to −0.65)

Abbreviations: C, control; Exp, experimental.

Table 7 Mean (95% CI) for each group and mean between-group difference (95% CI) for health care usage

Outcome	Exp (n=38)	Con (n=79)	Between-Group Difference (95% CI) Exp−Con
Cost of physiotherapy sessions (€), mean (95% CI)	1.105.45 (866 to 1.342.3)	1.472.2 (1.169.1 to 1.732)	−368.92 (−732.64 to −28.15)
Cost of rehabilitation consultations (€), mean (95% CI)	452.57 (342.6 to 562.54)	672.51 (562.54 to 782.48)	−303.01 (−535.64 to −151.21)

Abbreviations: C, control; Exp, experimental.

Cost analysis was performed according to the Andalusian Public Health Service unitary cost per physiotherapy session (€43.30) and rehabilitation consultation (first consultation: €232.63; follow-up consultation: €109.97). Applying this calculation to the results of our study, a savings per patient was estimated (table 7).

Discussion

Patients with bone and soft tissue injuries of the hand, wrist, and fingers clinically benefited from receiving a home exercise program using the ReHand app. These clinical improvements were accompanied by less consumption of health care resource.

First, for the primary outcome, between-group effect sizes were medium in favor of the experimental group. The mean between-group difference for changes in functional ability at 3 months, as measured by the QuickDASH (11.12 points) and PRWE (13.31 points), exceeded the reported MCID in the overall cohort. When analyzing the different subgroups (see supplementary material), although they showed similar results favoring the experimental group, the number of patients in each subgroup for the analysis was reduced and was insufficient to achieve statistical significance. Secondly, a reduction in health care resource usage was observed in the experimental group. In addition to fewer referrals to the rehabilitation service, patients in the experimental group referred to rehabilitation services received fewer face-to-face sessions. Blanquero et al also showed a reduction in physiotherapy sessions, rehabilitation consultations, and surgery consultations when patients received ReHand as a complement to the face-to-face therapy.[38] This can positively affect waiting list time, patient transportation to the hospital, and early discharge from rehabilitation service, as other authors have reported.[23,24]

In our study, we estimated the cost savings according to physiotherapy session and rehabilitation consultation. These savings could be higher in other countries. In example, Shah et al reported an average cost per physiotherapy session of $70-$90 in the United States in 2015.[2] These savings were only calculated for those patients who attended the rehabilitation service. Because the rate of referral to the rehabilitation service was reduced in the experimental group, a full estimate of the savings would require also considering the sessions for those patients who did not need to attend this service.

Shah et al[2] evaluated physical therapy and occupational therapy sessions after common hand procedures. They found an increase in prescribing patterns for therapy sessions in common pathologies like distal radius fractures or carpal tunnel syndrome. The authors highlighted that this increases the cost of care for these pathologies. Our results showing reduced referrals to the rehabilitation service may favor the sustainability of the services and reduce the costs of care for these pathologies.

There are several causes that can be proposed as an explanation for the superior patient clinical evolution in the experimental group and the consequently reduction in health care usage observed. Patients may feel more engaged with an interactive electronic device, enhancing adherence to home exercises. Adherence to treatment is a key factor with implications for treatment cost and effectiveness.[39] Current methods proposed to monitor or increase adherence to home exercises have proven to be unreliable: phone calls, signing contracts, written instructions, and self-reported methods such as diaries or exercises on video.[40-42] Patients in the experimental group received weekly phone calls by a physiotherapist who had access to adherence and performance data through the ReHand dashboard, which has to be considered as possible explanation for this study results.

Another possible explanation could be related to the effect of technology on patient adaptation and dosing. ReHand requires daily calibration so patients can adapt exercises to their pain-free range of motion, which could minimize pain during the exercises. Also, the ReHand algorithm system progresses through each exercise during patient evolution daily, which is more immediate than progression established in weekly sessions.

In addition, the sensorimotor enhancement due to the evidence-based exercises that can be performed using the touchscreen should be considered. Its implications exceed the peripheral injury in a specific tissue, affecting also the central nervous system levels. Peripheral tissue injury can provoke maladaptative changes in the nervous system[43] that generate the need to "relearn" movement.[44]

Sensorimotor deficits have been reported in patients with common hand, wrist, and finger conditions.[45] Also, injury,[46] hand surgery,[47] and immobilization affect the peripheral and central nervous systems, reducing muscle strength and voluntary activation and inducing neuroplastic changes.[48] Sensorimotor impairment and functional deficits has been shown even when receiving physical therapy sessions.[49] Therefore, sensorimotor-based treatment has been proposed by experts to encompass early and late phases of rehabilitation.[50]

Touchscreen-based apps have been proposed as a means of treatment for performing sensorimotor exercises for hand pathologies.[51,52] Touchscreens can offer motion-guided exercises to be performed using a touchscreen with determined parameters such as velocity of the movement, range of motion, and direction.[52,53] Feedback-guided exercises challenge the patient to reproduce a controlled and precise movement, which is the basis of neuromuscular control and proprioceptive training that have shown a positive effect on reorganization within the motor cortex of the central nervous system.[46] Larsen et al's study observed changes in the common corticospinal drive to spinal motoneurons involved in manual dexterity after the practice of motor exercises on a tablet device.[54]

The present study concludes a line of research that aimed to evaluate the effectiveness of ReHand used both as an adjunct to face-to-face therapy and as a sole intervention for the management of bone and soft tissue injuries of the wrist, hand, and/or fingers. Blanquero et al previously reported that ReHand in combination with face-to-face physiotherapy and occupational therapy sessions hastened return to work, reduced health care usage, and improved early recovery of strength and function.[38] The present study showed that this effectiveness of ReHand on clinical and health care resource-saving variables was observed both when ReHand was applied as the sole intervention and when ReHand was applied as an adjunct to treatment.

Study limitations

The main limitation of this study is that the allocation group was nonrandomized and based on possession of a tablet, which could lead to a biased sample. Although demographic and baseline outcomes did not present significant differences and ANCOVA analysis with baseline outcome as the covariate was performed, other unknown characteristics could be inherently different between groups. This study was a pragmatic trial that tests the effectiveness of an innovative intervention in a real-world context, as opposed to an efficacy trial, which is performed in controlled conditions. A limitation of this study was that adherence to the home exercise programs was not measured, which might have helped to determine the mechanism by which the clinical benefits occurred. Another limitation was that indirect costs such as days off work or transportation to clinic appointments were not included in the health care usage analysis.

Conclusions

Prescribing ReHand to patients with traumatic bone and soft tissue injuries of the hand, wrist, and fingers improves patients' functional ability and reduces the number of patients referred to rehabilitation consultation and the number of face-to-face physiotherapy sessions.

Supplier

a. Baseline hydraulic hand dynamometer, Saehan SH5001, Saehan Corp. b. Granmo Software, v7.12, Institut Municipal d'Investigació Mèdica. c. SPSS, IBM Corp.

Keywords

Exercise therapy; Health resources; Mobile applications; Physical therapy; Rehabilitation; Telerehabilitation

Corresponding author

Alejandro Suero-Pineda PT, MSci, Physiotherapy Department, Faculty of Nursing, Physiotherapy and Podiatry, University of Sevilla, c/ Avicena s/n, 41009 Sevilla, Spain. *E-mail address:* alesuepin@alum.us.es.

Acknowledgments

For their administrative and logistic support, we thank the staff of Hand Surgery, Physiotherapy, Occupational Therapy and Rehabilitation Services of Hospital Universitario Virgen Macarena and Hospital Universitario Virgen del Rocío. We thank the entire ReHand research team and the engineering team that developed ReHand, José Manuel López, Nieves Sánchez-Laulhé, Lorena Sarmiento, Manuel Herrera, and Santiago Soto Gómez, who has been entirely dedicated since inception of this project and made its initiation possible.

References

1. Robinson LS, Brown T, O'Brien L. Cost, profile, and postoperative resource use for surgically managed acute hand and wrist injuries with emergency department presentation. J Hand Ther 2021;34:29–36.
2. Shah RF, Zhang S, Li K, Baker L, Sox-Harris A, Kamal RN. Physical and occupational therapy use and cost after common hand procedures. J Hand Surg Am 2020;45. 289-97.e1.
3. Colen DL, Fox JP, Chang B, Lin IC. Burden of hand maladies in US emergency departments. Hand 2018;13:228–36.
4. De Putter CE, Selles RW, Polinder S, Panneman MJM, Hovius SER, Van Beeck EF. Economic impact of hand and wrist injuries: health-care costs and productivity costs in a population-based study. J Bone Joint Surg Am 2012;94:e56.
5. Handoll HHG, Elliott J. Rehabilitation for distal radial fractures in adults. Cochrane Database Syst Rev 2006;2015:CD003324.

6. Huisstede BM, van den Brink J, Randsdorp MS, Geelen SJ, Koes BW. Effectiveness of surgical and postsurgical interventions for carpal tunnel syndrome—a systematic review. Arch Phys Med Rehabil 2018;99. 1660-80.e21.
7. Hardy M a. Principles of metacarpal and phalangeal fracture management: a review of rehabilitation concepts. J Orthop Sports Phys Ther 2004;34:781–99.
8. Wouters RM, Tsehaie J, Hovius SER, Dilek B, Selles RW. Postoperative rehabilitation following thumb base surgery: a systematic review of the literature. Arch Phys Med Rehabil 2018;99. 1177-212.e2.
9. Huisstede BMA, Hoogvliet P, Coert JH, Fridén J. Dupuytren disease: European hand surgeons, hand therapists, and physical medicine and rehabilitation physicians agree on a multidisciplinary treatment guideline: results from the HANDGUIDE study. Plast Reconstr Surg 2013;132:964–76.
10. Sultana SS, Macdermid JC, Grewal R, Rath S. The effectiveness of early mobilization after tendon transfers in the hand: a systematic review. J Hand Ther 2013;26:1–21.
11. Neiduski RL, Powell RK. Flexor tendon rehabilitation in the 21st century: a systematic review. J Hand Ther 2019;32:165–74.
12. Wong AL, Wilson M, Girnary S, Nojoomi M, Acharya S, Paul SM. The optimal orthosis and motion protocol for extensor tendon injury in zones IV-VIII: a systematic review. J Hand Ther 2017;30:447–56.
13. Hwang R, Elkins MR. Telephysiotherapy. J Physiother 2020;66:143–4.
14. Ali EE, Chew L, Yap KY-L. Evolution and current status of mhealth research: a systematic review. BMJ Innov 2016;2:33–40.
15. Albabtain AF, AlMulhim DA, Yunus F, Househ M. The role of mobile health in the developing world: a review of current knowledge and future trends. IEEE Access 2017;5:11540–56.
16. Hamine S, Gerth-Guyette E, Faulx D, Green BB, Ginsburg AS. Impact of mHealth chronic disease management on treatment adherence and patient outcomes: a systematic review. J Med Internet Res 2015;17:1–15.
17. Blanquero J, Cortés-Vega MD, García-Frasquet MÁ, Sánchez-Laulhé PR, Nieto Díaz de los Bernardos MI, Suero-Pineda A. Exercises using a touchscreen tablet application improved functional ability more than an exercise program prescribed on paper in people after surgical carpal tunnel release: a randomised trial. J Physiother 2019;65:81–7.
18. Pastora-Bernal JM, Martín-Valero R, Barón-López FJ, Estebanez-Pérez MJ. Evidence of benefit of telerehabilitation after orthopedic surgery: a systematic review. J Med Internet Res 2017;19:142.
19. Agostini M, Moja L, Banzi R, et al. Telerehabilitation and recovery of motor function: a systematic review and meta-analysis. J Telemed Telecare 2015;21:202–13.
20. Shukla H, Nair SR, Thakker D. Role of telerehabilitation in patients following total knee arthroplasty: evidence from a systematic literature review and meta-analysis. J Telemed Telecare 2017;23:339–46.
21. Jiang S, Xiang J, Gao X, Guo K, Liu B. The comparison of telerehabilitation and face-to-face rehabilitation after total knee arthroplasty: a systematic review and meta-analysis. J Telemed Telecare 2018;24:257–62.
22. Dávila Castrodad IM, Recai TM, Abraham MM, et al. Rehabilitation protocols following total knee arthroplasty: a review of study designs and outcome measures. Ann Transl Med 2019;7(Suppl 7):S255.
23. Galea MDF. Telemedicine in rehabilitation. Phys Med Rehabil Clin N Am 2019;30:473–83.
24. Howard IM, Kaufman MS. Telehealth applications for outpatients with neuromuscular or musculoskeletal disorders. Muscle Nerve 2018;58:475–85.
25. Cottrell MA, Galea OA, O'Leary SP, Hill AJ, Russell TG. Real-time telerehabilitation for the treatment of musculoskeletal conditions is effective and comparable to standard practice: a systematic review and meta-analysis. Clin Rehabil 2017;31:625–38.
26. Carl CF. Adoption of telerehabilitation in a developing country before and during the COVID-19 pandemic. Ann Phys Rehabil Med 2020;63:563–4.
27. Chang MC, Boudier-Revéret M. Usefulness of telerehabilitation for stroke patients during the COVID-19 pandemic. Am J Phys Med Rehabil 2020;99:582.
28. Rosales RS, García-Gutierrez R, Reboso-Morales L, Atroshi I. The Spanish version of the Patient-Rated Wrist Evaluation outcome measure: cross-cultural adaptation process, reliability, measurement error and construct validity. Health Qual Life Outcomes 2017;15:1–9.
29. Wormald JCR, Geoghegan L, Sierakowski K, et al. Site-specific patient-reported outcome measures for hand conditions: systematic review of development and psychometric properties. Plast Reconstr Surg Glob Open 2019;7:e2256.
30. Kennedy CA, Beaton DE, Smith P, et al. Measurement properties of the QuickDASH (Disabilities of the Arm, Shoulder and Hand) outcome measure and crosscultural adaptations of the QuickDASH: a systematic review. Qual Life Res 2013;22:2509–47.
31. Rosales RS, Diez De La Lastra I, McCabe S, Ortega Martinez JI, Hidalgo YM. The relative responsiveness and construct validity of the Spanish version of the DASH instrument for outcomes assessment in open carpal tunnel release. J Hand Surg Eur Vol 2009;34:72–5.
32. Southam M, Driessens S, Burton C, Pope R, Thurnwald P. A retrospective cohort study of QuickDASH scores for common acute trauma conditions presenting for hand therapy. J Hand Ther 2017;30:41–8.
33. MacDermid JC, Turgeon T, Richards RS, Beadle M, Roth JH. Patient Rating of Wrist Pain and Disability: a reliable and valid measurement tool. J Orthop Trauma 1998;12:577–86.
34. Irwin CB, Sesto ME. Reliability and validity of the multiaxis profile dynamometer with younger and older participants. J Hand Ther 2010;23:281–8. quiz 289.
35. Hawker GA, Mian S, Kendzerska T, French M. Measures of adult pain: visual analog scale for pain (VAS Pain), numeric rating scale for pain (NRS Pain), McGill Pain Questionnaire (MPQ), Short-Form McGill Pain Questionnaire (SF-MPQ), Chronic Pain Grade Scale (CPGS), Short Form-36 Bodily Pain Scale (SF). Arthritis Care Res (Hoboken) 2011;63:S240–52.
36. Castarlenas E, de la Vega R, Jensen MP, Miró J. Self-report measures of hand pain intensity: current evidence and recommendations. Hand Clin 2016;32:11–9.
37. Grice KO, Vogel KA, Le V, Mitchell A, Muniz S, Vollmer MA. Adult norms for a commercially available nine hole peg test for finger dexterity. Am J Occup Ther 2003;57:570–3.
38. Blanquero J, Cortés-Vega M-D, Rodríguez-Sánchez-Laulhé P, et al. Feedback-guided exercises performed on a tablet touchscreen improve return to work, function, strength and healthcare usage more than an exercise program prescribed on paper for people with wrist, hand or finger injuries: a randomised trial. J Physiother 2020;66:236–42.
39. Jack K, McLean SM, Moffett JK, Gardiner E. Barriers to treatment adherence in physiotherapy outpatient clinics: a systematic review. Man Ther 2010;15:220–8.
40. Cole T, Robinson L, Romero L, O'Brien L. Effectiveness of interventions to improve therapy adherence in people with upper limb conditions: a systematic review. J Hand Ther 2019;32:175–83. e2.
41. Murphy CA. Adherence to a home exercise program after signing a contract. J Hand Ther 2016;29:375–6.
42. Lyngcoln A, Hons PT, Taylor N, Pizzari T. The relationship between adherence to hand therapy and short-term outcome after distal radius fracture. J Hand Ther 2004;18:2–8.
43. Karagiannopoulos C, Sitler M, Michlovitz S, Tucker C, Tierney R. Responsiveness of the active wrist joint position sense test after distal radius fracture intervention. J Hand Ther 2016;29:474–82.
44. De Jong BM, Coert JH, Stenekes MW, Leenders KL, Paans AMJ, Nicolai JPA. Cerebral reorganisation of human hand movement following dynamic immobilisation. Neuroreport 2003;14:1693–6.
45. Valdes K, Naughton N, Algar L. Sensorimotor interventions and assessments for the hand and wrist: a scoping review. J Hand Ther 2014;27:272–86.
46. Röijezon U, Clark NC, Treleaven J. Proprioception in musculoskeletal rehabilitation. Part 1: basic science and principles of assessment and clinical interventions. Man Ther 2015;20:368–77.

47. Lundborg G. Brain plasticity and hand surgery: an overview. J Hand Surg Br Eur Vol 2000;25:242–52.
48. Clark BC, Mahato NK, Nakazawa M, Law TD, Thomas JS. The power of the mind: the cortex as a critical determinant of muscle strength/weakness. J Neurophysiol 2014;112:3219–26.
49. Karagiannopoulos C, Sitler M, Michlovitz S, Tucker C, Tierney R. A descriptive study on wrist and hand sensori-motor impairment and function following distal radius fracture intervention. J Hand Ther 2013;26:204–15.
50. Karagiannopoulos C, Michlovitz S. Rehabilitation strategies for wrist sensorimotor control impairment: from theory to practice. J Hand Ther 2016;29:154–65.
51. Short N, LaRowe J, Treherne TN, et al. Exploring the needs of certified hand therapists regarding electronic applications. J Hand Ther 2018;31:52–8.
52. Algar L, Valdes K. Using smartphone applications as hand therapy interventions. J Hand Ther 2014;27:254–7.
53. Rand D, Zeilig G, Kizony R. Rehab-let: touchscreen tablet for self-training impaired dexterity post stroke: study protocol for a pilot randomized controlled trial. Trials 2015;16:277.
54. Larsen LH, Jensen T, Christensen MS, Lundbye-Jensen J, Langberg H, Nielsen JB. Changes in corticospinal drive to spinal motoneurones following tablet-based practice of manual dexterity. Physiol Rep 2016;4:e12684.