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Digital rehabilitation for hand and wrist pain: a single-arm prospective longitudinal cohort study

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Abstract

Introduction: Wrist and hand represent the third most common body part in work-related injuries, being associated with long-term absenteeism. Telerehabilitation can promote access to treatment, patient adherence, and engagement, while reducing health care–related costs.

Objective: Report the results of a fully remote digital care program (DCP) for wrist and hand pain (WP).

Methods: A single-arm interventional study was conducted on individuals with WP applying for a DCP. Primary outcome was the mean change in the Numerical Pain Rating Scale after 8 weeks (considering a minimum clinically important change of 30%). Secondary outcomes were: disability (Quick Disabilities of the Arm, Shoulder, and Hand questionnaire), analgesic intake, surgery intention, mental health (patient health questionnaire [PHQ-9] and generalized anxiety disorder [GAD-7]), fear-avoidance beliefs (FABQ-PA), work productivity and activity impairment, and engagement.

Results: From 189 individuals starting the DCP, 149 (78.8%) completed the intervention. A significant pain improvement was observed (51.3% reduction (2.26, 95% CI 1.73; 2.78)) and 70.4% of participants surpassing minimum clinically important change. This change correlated with improvements in disability (52.1%), FABQ-PA (32.2%), and activities impairment recovery (65.4%). Improvements were also observed in other domains: surgery intent (76.1%), mental health (67.0% in anxiety and 72.7% in depression), and overall productivity losses (68.2%). Analgesic intake decreased from 22.5% to 7.1%. Mean patient satisfaction score was 8.5/10.0 (SD 1.8).

Conclusions: These findings support the feasibility and utility of a fully remote DCP for patients with WP. Clinically significant improvements were observed in all health-related and productivity-related outcomes, alongside very high patient adherence rates and satisfaction. This study strengthens that management of WP is possible through a remote DCP, decreasing access barriers and potentially easing health care expenditure.

Keywords: Musculoskeletal pain, Physical therapy, Telerehabilitation, Digital therapeutic, eHealth

1. Introduction

Wrist or hand pain (WP) is very common among the adult population, with a prevalence rate of approximately 19.1%, being the third most common work-related injury.[31,90] Over the past few decade, 2.6 million annual hand and wrist injuries were estimated in a nationwide database study in the United States.[34] Wrist or

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hand pain conditions impose significant disability, affecting leisure and work activities,[20,63,67] being frequently associated with long-term absenteeism.[90] Collectively, this translates into an average $6951 total cost per case or $8297 considering health economic evaluations (in 2015 U.S. dollars), with indirect costs (work absenteeism) being a major driver.[77]

Major risk factors associated with WP conditions include female sex,[31,54,96] occupations with high mechanical demands (including handling of heavy material or vibration tools)[29,31,68] or sustained repetitive movements (eg, computer use),[4,30,54,57,81] and high psychological stress, work-related or otherwise.[31]

There is no consensus on best practices to manage WP conditions, with most guidelines advocating for stronger evidence. Surgical interventions are mainly reserved for refractory or severe cases,[11,93] while conservative treatments have been advocated in most conditions.[41,49,50,58,65,79] Among these, exercise is one the most frequently studied interventions with positive results reported for function and pain.[2,70,71,80,92] Exercise has the advantage of inducing systemic and long-lasting effects, encompassing not only biomechanical and functional aspects but also influencing central pain processing,[27,89,91] metabolic mechanisms,[14] sleep,[3,46] and mental health.[38,52] In 1 randomized controlled trial (RCT), patients in a waiting list for carpal tunnel surgery who underwent exercise-based interventions combined with education and splinting had a lower likelihood of proceeding to surgery.[55] Despite the importance of early interventions to prevent progression, access to care remains poor because of unavailable health care resources (amplified during the COVID-19 pandemic[85]), treatment time, and travel barriers.[13,21,56]

Telerehabilitation, which consists of remotely managing rehabilitation using communication-based technologies, shows great potential in overcoming such challenges, improving WP assessment[62] and care,[1,8,9,53,84] promoting patient adherence and empowerment,[44] reducing disability, and facilitating return to work.[8]

Previously, we demonstrated the effectiveness of tailored digital care programs (DCP) in the rehabilitation of other musculoskeletal (MSK) conditions.[15–18,22] This study aims to assess the feasibility, engagement, and clinical outcomes of a remote multimodal DCP integrating exercise and education (including disease management and cognitive behavioral therapy [CBT]) in patients with WP. Our hypothesis was that the aforementioned outcomes would be comparable with other conventional or digital approaches.

2. Methods

2.1. Study design

This single-arm, decentralized study assessed clinical-related and engagement-related outcomes in patients with WP after a multimodal DCP. Approval was obtained for this prospective study from the New England Institutional Review Board (number 120190313), and the trial was registered on ClinicalTrials.gov (NCT04092946) on September 17, 2019. The home-based DCP was delivered between August 1, 2020, and October 12, 2021.

2.2. Participants

Beneficiaries of employers or health plans older than 18 years and reporting WP were offered the opportunity to apply to SWORD Health's DCP through a dedicated website. Wrist or hand pain was defined as a pain condition affecting the wrist, hand, or fingers in the context of neuropathy, tendinopathy, osteoarthritis, or sprain or fracture. Exclusion criteria included (1) presence of a health condition incompatible with at least 20 minutes of light-to-moderate exercise (eg, cardiac, respiratory), (2) cancer requiring active treatment, (3) rapidly progressive loss of strength or numbness in the arms or legs, and (4) unexplained change in bowel or urinary function in the previous 2 weeks.

Informed consent was obtained from all participants. To prevent the risk of selection bias, consecutive participants were enrolled until the cut-off date of August 12, 2021.

2.3. Intervention

This telerehabilitation intervention combines individually tailored exercises, education, and CBT during an 8-week program (**Fig. 1**). On enrollment, a physical therapist (PT) is assigned to each participant. The PT is responsible for program customization and monitoring, through the digital therapist (DT).

The DT is an FDA-listed class II medical device comprising a dedicated tablet with a mobile app, inertial motion trackers (IMU), and a cloud-based portal. The tablet displays the prescribed exercises through audio–videos, while motion sensors, both camera-based (tablet camera) and IMU-based, provide real-time feedback on performance to the participant. This allows individuals to perform exercise sessions independently at home (3 sessions per week are typically recommended). The exercise prescription was based on current evidence and clinical guidelines.[25,49,50,55,70,79] Data obtained from the exercise sessions are stored on a cloud-based platform, being asynchronously monitored through a web-based portal by the assigned PT who adjusts the exercises according to the patients' performance and progression (Supplementary Table S1, available at http://links.lww.com/PR9/A166). The education and CBT components were developed according to current evidence and clinical guidelines.[12,49,97] The main topics addressed include ergonomics, risk behaviors, as well as pain reconceptualization, fear-avoidance, and active coping skills. A multidisciplinary team (including psychiatrists and psychologists) developed the CBT component into interactive modules. Those were based on third-generation techniques, such as acceptance and commitment therapy, mindfulness, and empathy-focused therapy. The educational articles and interactive modules were delivered through a dedicated smartphone app. Bidirectional communication between participants and PTs was ensured through a built-in secure chat feature on the same smartphone app (with at least 1 touchpoint each week by the PT) and through synchronous video calls between the PT and the member (at least once every 4 weeks).

2.4. Outcomes

Outcome assessments were recorded at baseline, and 4 and 8 weeks, while mean changes were calculated between baseline and the 8-week primary end point. Primary outcome was self-reported pain level, using the Numerical Pain Rating Scale (NPRS), through the question: "Please rate your average pain over the last 7 days" from 0 (no pain at all) to 10 (worst pain imaginable).[98] Secondary outcomes assessed the following clinical and engagement domains:

(1) Disability: Quick Disabilities of the Arm, Shoulder, and Hand questionnaire (QuickDASH). This scale consists of 11 items scored from 0% to 100%, with higher scores indicating worse functioning.[82,100]
(2) Anxiety: Generalized Anxiety Disorder (GAD-7) measured on a 7-item scale (range 0–21).[83]

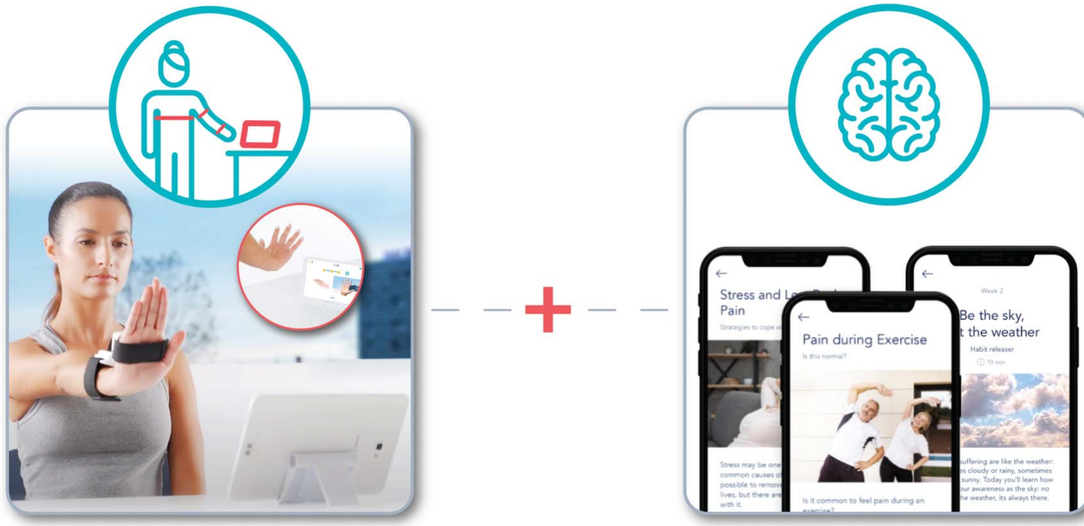

Figure 1. System components. The left figure shows the motion tracker setup (tablet camera–based and inertial motion trackers–based motion capture) and the mobile app displaying the audio–video instructions during the exercise and real-time biofeedback to patients. The right figure depicts the education and cognitive behavioral therapy components of the digital care program.

(3) Depression: Patient Health (PHQ-9), a 9-item questionnaire (range 0–27).[7,51,83]

A threshold equal or greater than 5 signifies at least mild anxiety (GAD-7) or depression (PHQ-9).[51]

(1) Fear-avoidance beliefs (FAB): FAB questionnaire evaluating physical activity (FABQ-PA), which includes 5 items scored on a 7-option Likert scale (0–24).[33]
(2) Work productivity and activity impairment (WPAI) for general health questionnaire: evaluated in employed participants (WPAI overall: combining presenteeism and absenteeism from work), presenteeism (WPAI work), absenteeism (WPAI time), and in all participants for not work-related activity impairment (WPAI activity).[69]
(3) Analgesic consumption: binary variable based on the question, "Are you currently taking any pain medication?"
(4) Surgery likelihood: continuous variable based on the question, "How likely are you to have surgery to address your condition in the next 12 months?" (range 0—not at all likely; 100—extremely likely).
(5) Engagement: measured through completion of the program (considered as retention rate), number of completed exercise sessions, number of sessions performed per week, and overall satisfaction evaluated by the question: "On a scale from 0 to 10, how likely is it that you would recommend this intervention to a friend or neighbor?"

2.5. Safety and adverse events

Physical therapists continuously monitored pain and fatigue scores (0–10 score) based on electronic questions answered by the participants at the end of each exercise session, as well as any adverse events reported by members through several communication channels.

2.6. Data availability

All relevant data are provided within the article or as supplementary material (available at http://links.lww.com/PR9/A166). The protocol, deidentified data, and analysis codes may be provided on reasonable request to the corresponding author.

2.7. Statistical analysis

Study population demographics and clinical data, as well as usability metrics are characterized through descriptive statistics. Participants were considered dropouts if they did not perform any session for 28 consecutive days. Participants were still considered if they were compliant with the intervention but failed to complete a given reassessment survey.

Differences between completers and noncompleters (ie, who dropped out or were excluded after program start) at baseline were assessed through χ^2 tests for categorical variables and independent sample *t* tests or one-way ANOVA with Bonferroni post hoc for continuous variables.

Outcome change trajectories were modeled using latent growth curve analysis (LGCA), following an intent-to-treat principle. Latent growth curve analysis belongs to the same family of linear mixed-effects modeling but uses a structural equation model[61] (Supplementary Figure 1 presents the structural equation and path diagram used for the LGCA, available at http://links.lww.com/PR9/A166), having the advantage of providing a measure of model fitness (eg, how well the model explains the data set). Each trajectory is represented by an intercept (baseline values) and slope (estimated linear change over time). Latent growth curve models treat time as a continuous variable, do not require equality of variance of residuals at each time point, acknowledges that repeated measures on the same individual are correlated, and provide estimates robust to attrition bias because it handles missing data through the use of full information maximum likelihood (FIML) estimation.[23,32,47,74] The FIML method handles missing data by using all of the subject's available data to calculate maximum likelihood estimates, outperforming other modern imputation models such as multiple imputation by chained equations (MICE) or listwise deletion.[73,101]

Given the high prevalence of carpal tunnel syndrome within WP (3% in the general population and ~8% in the working population[11,19]), a subgroup analysis of this cohort was performed. Models were adjusted for covariates, ie, sex, age, and body mass index (BMI). A robust sandwich estimator for standard errors was used in all model estimations. Two analyses were performed including the entire cohort and filtering at baseline for relevant scores: (1) >0 score for surgery intent and WPAI and (2) ≥5 score for GAD-7 and PHQ-9. A conditional analysis was also performed to assess the influence of age, sex, BMI, and type of occupation (eg, white vs blue collar) covariates. Model fit estimation was assessed using χ^2 test, confirmatory fit index (CFI), root mean square error of approximation (RMSEA), and standardized root mean square residual (SRMR).[10,42]

Association of baseline variables with the probability of being a responder for pain reduction was assessed through logistic regression, considering a minimum clinically important change (MCIC) of 30% between baseline and treatment end.[24]

Associations between outcome changes were assessed through bivariate correlations (Pearson r). Significance levels were set at $P < 0.05$ in all analyses. Latent growth curve analysis was coded using R (version 1.4.1717), and all other analyses were performed using SPSS (version 17.0, SPSS Inc, Chicago, IL).

3. Results

As presented in the study flow diagram (**Fig. 2**), 255 participants were screened for eligibility, 8 (3.1%) declined participation, and 58 (22.7%) were excluded. Therefore, 189 participants from 41 states within the United States started the program. Program completion rate was 78.8% (149/189).

3.1. Baseline characteristics

Baseline demographics of the entire cohort (N = 189) and of the carpal tunnel syndrome (CTS) subgroup (N = 50) are given in **Table 1**.

Comparing completers (N = 149) with noncompleters (N = 40), the latter were younger ($P = 0.029$), presented with more acute conditions ($P = 0.001$), and had lower levels of disability ($P = 0.031$) at baseline than completers (Supplementary Table S2, available at http://links.lww.com/PR9/A166).

3.2. Clinical outcomes

Each outcome variable had its change modeled through LGC, following an intent-to-treat principle (N = 189) with the respective trajectory parameters and *P*-values presented in Supplementary Table S3, http://links.lww.com/PR9/A166. The results are reported following unconditional (**Table 2**) and conditional models (Supplementary Table S4, available at http://links.lww.com/PR9/A166), with the latter presenting the impact of covariates.

3.3. Primary outcome

3.3.1. Pain

Significant reduction was observed for pain across the intervention ($P < 0.001$, Supplementary Table S2, available at http://links.lww.com/PR9/A166), with a mean change of 51.3% observed (2.26, 95% CI 1.73; 2.78) (**Table 2**). Female patients reported more pain at program start ($P < 0.001$), which had no impact on recovery trajectories (**Fig. 3**; Supplementary Table S4, available at http://links.lww.com/PR9/A166). Considering the recommended MCIC of 30% for pain,[24] an odds ratio (OR) of 2.38 (95% CI 1.35; 4.38) was observed, corresponding to 70.4% response rate ($P < 0.001$). The OR for being a responder was not influenced by age, sex, or mental health status at baseline (Supplementary Table S5, available at http://links.lww.com/PR9/A166).

3.4. Secondary outcomes

3.4.1. Quick Disabilities of the Arm, Shoulder, and Hand Questionnaire

We observed a significant reduction in QuickDASH of 13.84 points (95% CI 10.77; 17.12, **Table 2**) representing an overall change of 52.1%. Female patients, older participants, and those

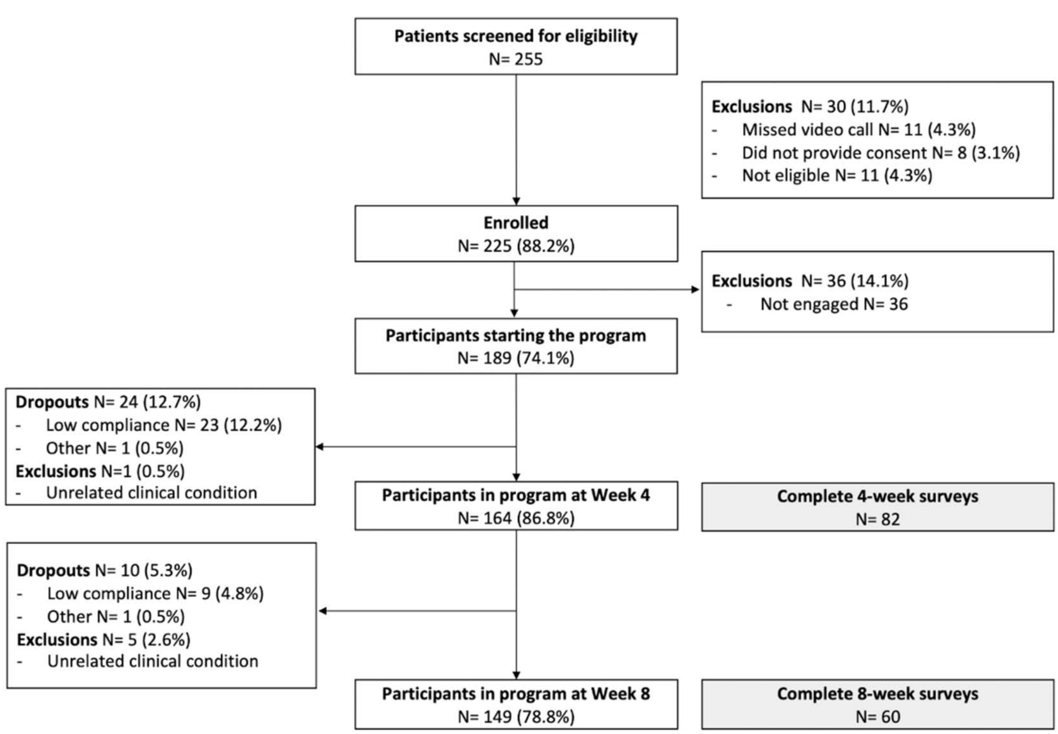

Figure 2. Study flow diagram.

Table 1

Baseline characteristics of study participants: entire cohort (N = 189) and carpal tunnel syndrome (N = 50) subgroups.

Characteristic	Entire cohort (N = 189)	Carpal tunnel syndrome (N = 50)
Age (y), mean (SD)	47.3 (11.1)	46.0 (10.4)
Age categories (y), N (%):		
<25	1 (0.5)	0 (0.0)
25–40	59 (31.2)	16 (32.0)
40–60	104 (55.0)	30 (60.0)
>60	25 (13.2)	4 (8.0)
Sex, N (%)		
Female	115 (60.8)	30 (60.0)
Male	73 (38.6)	20 (40.0)
Nonbinary	1 (0.5)	0 (0.0)
BMI, mean (SD)	28.7 (6.8)	29.8 (6.2)
BMI categories, N (%):		
Underweight (<18.5)	2 (1.1)	0 (0.0)
Normal (18.5–25)	62 (32.8)	12 (24.0)
Overweight (25–30)	66 (34.9)	20 (40.0)
Obese (30–40)	45 (23.8)	13 (26.0)
Obese grade III (>40)	14 (7.4)	5 (10.0)
Side		
Left	55 (29.1)	56 (71.8)
Right	129 (68.3)	20 (25.6)
Both	5 (2.6)	2 (2.6)
Wrist condition, N (%):		
Carpal tunnel syndrome	50 (26.5)	—
De Quervain tenosynovitis	16 (8.5)	—
Other tenosynovitis	4 (2.1)	—
Tendinopathy	45 (23.8)	—
Chronic nonspecific wrist pain	28 (14.8)	—
Wrist or hand osteoarthritis	16 (8.5)	—
Sprain or fracture	14 (7.4)	—
Systemic diseases	11 (5.8)	—
Dorsal wrist syndrome	3 (1.6)	—
Other	2 (1.1)	—
Pain duration, N (%):		
Acute (<12 wk)	69 (36.5)	18 (36.0)
Chronic (>12 wk)	120 (63.5)	32 (64.0)
Employment status, N (%):		
Employed (part-time or full-time)	174 (92.1)	46 (92.0)
Unemployed (not working or retired)	15 (7.9)	4 (8.0)
Occupation type, N (%):		
White collar	56 (29.6)	14 (28.0)
Blue collar	96 (50.8)	27 (54.0)
Other (eg, retired)	37 (19.6)	9 (18.0)

BMI, body mass index.

with higher BMI levels reported higher QuickDASH baseline levels, but overall recovery trajectories were not influenced by any covariates with the exception for female sex, which was associated with a faster-paced recovery (−0.85 per week, $P = 0.029$) (**Fig. 3**; Supplementary Table S4, available at http://links.lww.com/PR9/A166). QuickDASH improvement was strongly correlated with pain reduction ($r[59] = 0.659$, $P < 0.001$).

3.4.2. Analgesic usage

Only a quarter of the participants (22.5%, 42/187) reported taking analgesics at baseline. Despite significant missing data for this outcome, an overall reduction of analgesic usage was observed, with only 7.1% of participants (4/56) still taking analgesics by study end.

3.4.3. Surgery intent

Willingness to pursue surgery decreased at a pace of −2.45 points (0.03) per week ($P < 0.001$), resulting in a reduction of 76.1% (19.63, 95% CI 14.69; 24.56) at the end of the intervention (**Table 2**). Participants with higher BMI scores at baseline reported greater willingness to undergo surgery; however, recovery trajectories were not influenced by any covariates (Supplementary Tables S4, available at http://links.lww.com/PR9/A166). The overall change in surgery likelihood was correlated with disability (QuickDASH) recovery ($r[59] = 0.291$, $P = 0.024$).

3.4.4. Mental health and fear-avoidance beliefs

Significant improvement was observed for both mental health indicators ($P < 0.001$) in participants with at least mild symptoms at baseline, revealing a mean change until program end of 67.0% for GAD-7 (5.54 points, 95% CI: 1.22; 9.87) and 72.7% for PHQ-9 (5.82 points, 95% CI: 3.69; 7.95). Individuals with white-collar occupations or higher BMI presented higher depression levels at baseline ($P = 0.001$ and $P = 0.024$, respectively), despite having no impact on recovery pace (Supplementary Table S4, available at http://links.lww.com/PR9/A166). Regarding FAB, a significant

Table 2

Outcome changes between baseline and 8 weeks: intent-to-treat approach (unconditional model).

Outcome, mean (95% CI)	N	Baseline	End-of-program	Mean change	% Change
Pain level	187	4.40 (4.09; 4.72)	2.14 (1.68; 2.60)	2.26 (1.73; 2.78)	51.3
QuickDASH	189	26.56 (24.38; 28.74)	12.72 (10.07; 15.37)	13.84 (10.77; 17.12)	52.1
Surgery intent > 0	101	25.79 (21.44; 30.14)	6.16 (2.30; 10.02)	19.63 (14.69; 24.56)	76.1
Surgery intent	187	13.71 (10.64; 16.78)	4.51 (2.19; 6.83)	9.20 (5.98; 12.42)	67.1
FABQ-PA	188	11.07 (10.29; 11.85)	7.50 (6.04; 8.96)	3.57 (2.12; 5.02)	32.2
GAD-7 ≥ 5	38	8.28 (7.05; 9.50)	2.73 (0.00; 6.60)	5.54 (1.22; 9.87)	67.0
GAD-7	189	2.53 (2.00; 3.05)	1.14 (0.40; 1.89)	1.38 (0.53; 2.23)	54.7
PHQ-9 ≥ 5	35	8.00 (6.88; 9.13)	2.18 (0.27; 4.09)	5.82 (3.69; 7.95)	72.7
PHQ-9	189	2.24 (1.74; 2.74)	0.71 (0.21; 1.21)	1.53 (0.93; 2.12)	68.2
WPAI overall > 0	93	28.00 (23.90; 32.10)	8.89 (3.48; 14.30)	19.11 (12.43; 25.79)	68.2
WPAI overall	158	16.22 (13.08; 19.36)	6.88 (3.61; 10.15)	9.34 (5.14; 13.54)	57.6
WPAI work > 0	92	27.66 (23.75; 31.58)	8.82 (3.17; 14.47)	18.84 (12.01; 25.67)	68.1
WPAI work	158	15.84 (12.77; 18.91)	6.90 (3.54; 10.26)	8.94 (4.71; 13.17)	56.4
WPAI activity > 0	142	32.45 (29.08; 35.81)	11.22 (7.41; 15.03)	21.23 (16.83; 25.62)	65.4
WPAI activity	189	24.39 (21.15; 27.62)	9.58 (6.42; 12.74)	14.81 (10.88; 18.74)	60.7

Analyses were performed both for unfiltered cases and filtering for above zero (>0) for surgery intent (individuals with intention to undergo surgery at baseline) and WPAI (individuals with productivity impairment at baseline), and above or equal to 5 (≥5) points for GAD-7 and PHQ-9 (individuals with at least mild anxiety and depression at baseline).

FABQ-PA, fear-avoidance beliefs questionnaire for physical activity; GAD-7, generalized anxiety disorder 7-item scale; PHQ-9, patient health 9-item questionnaire; QuickDASH, quick disabilities of the arm, shoulder, and hand questionnaire; WPAI, work productivity and activity impairment questionnaire.

improvement of 32.2% (mean change 3.57, 95% CI 2.12; 5.02) was observed, with female patients recovering at a faster pace (−0.39, $P = 0.040$). Fear-avoidance beliefs improvement was correlated with pain reduction ($r[46] = 0.409$, $P = 0.005$) and QuickDASH reduction ($r[47] = 0.583$, $P < 0.001$).

3.4.5. Work productivity

Productivity recovery improved significantly by 68.2% on the WPAI overall score (mean change 19.11, 95% CI 12.43; 25.79, $P < 0.001$), 68.1% on the WPAI work score (mean change 18.84, 95% CI 12.01; 25.67, $P < 0.001$), and 65.4% on the WPAI activity

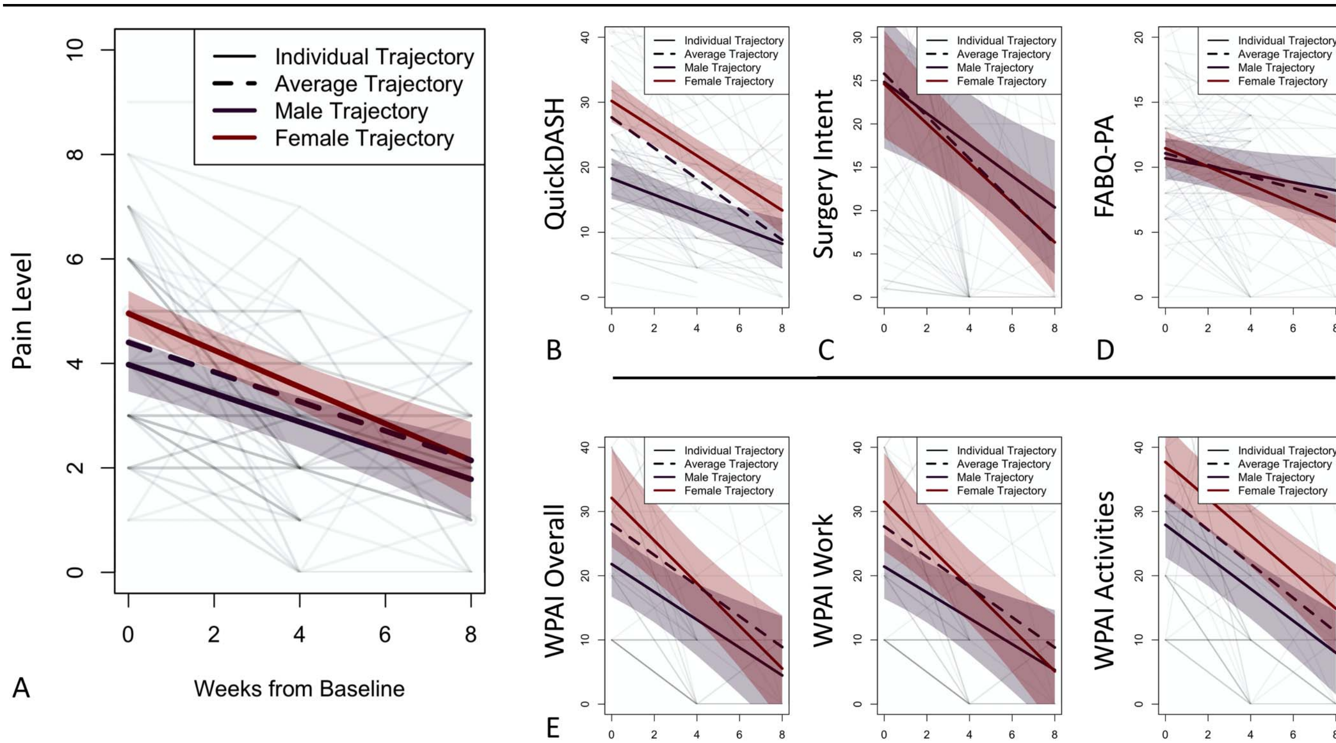

Figure 3. Longitudinal changes across time and per sex for all filtered variables. Individual trajectories are depicted in lighter lines (with darker lines meaning overlap of trajectories), while average trajectories are depicted in bold lines, with shadowing depicting 95% confidence intervals. (A) Primary outcome: pain level; (B–E) secondary outcomes: (B) QuickDASH; (C) surgery intent; (D) FABQ-PA; and (E) WPAI overall, WPAI work, and WPAI activity. Cases were filtered according to the following baseline thresholds—surgery intent and WPAI scores >0 points. FABQ-PA, fear-avoidance beliefs questionnaire for physical activity; QuickDASH, quick disabilities of the arm, shoulder, and hand questionnaire; WPAI, work productivity and activity impairment.

score (mean change 21.23 95% CI 16.83; 25.62, $P < 0.001$). Regarding WPAI time, only 11 individuals (of 158) had some degree of absenteeism at baseline, which reduced to 4 individuals (of 47) at program end. Female patients and individuals with higher BMI scores reported both higher overall productivity and activity impairment at baseline, while those with white-collar occupations had lower activity impairment at baseline. Any covariates influenced recovery trajectories (Supplementary Table S4, available at http://links.lww.com/PR9/A166). Overall productivity recovery was correlated with a lower likelihood to pursue surgery ($r[48] = 0.364$, $P = 0.011$). Activity impairment recovery was correlated with pain reduction ($r[59] = 0.401$, $P = 0.002$), disability reduction ($r[60] = 0.466$, $P < 0.001$), and FABQ-PA reduction ($r[47] = 0.313$, $P = 0.032$).

3.5. Engagement and usability

An average of 20.3 (13.8) sessions were performed by participants, and engagement levels were high, particularly in the first 4 weeks—3.0 (1.7) sessions, with an overall 2.5 (1.7) sessions a week on average in the entire cohort and 3.0 (1.6) sessions a week in completers. Total average exercise duration was 390.4 (277.2) minutes. On average, participants read 3.4 (5.1) educational content pieces. Average satisfaction was 8.5 (1.8).

3.6. Subgroup analysis: carpal tunnel syndrome

Considering the high prevalence of carpal tunnel syndrome,[11,19] a subgroup analysis was performed. As observed in **Table 1**, all baseline subgroup characteristics were similar to the entire cohort. An LGCA of this subgroup is presented in Supplementary Table S6 (available at http://links.lww.com/PR9/A166) and respective outcome changes in **Table 3**. The recovery profile of each outcome measure was very similar to that previously observed for the entire cohort (Supplementary Table S7, available at http://links.lww.com/PR9/A166). Female patients presented with greater disability and productivity impairment at baseline ($P = 0.035$ and $P = 0.049$, respectively), but sex did not affect recovery pace. Older participants had lower FABQ-PA, GAD-7, and productivity impairment at baseline but recovered at a slower pace (Supplementary Table S8, available at http://links.lww.com/PR9/A166).

4. Discussion

4.1. Main findings

This multimodal DCP was able to foster high engagement and completion rates, which paralleled statistically significant improvements in all outcome measures. A significant reduction in pain was observed (51.3%), above the reported MCIC of 30%,[24] corresponding to a 70.4% response rate. Importantly, this recovery was correlated with improvements in several secondary outcomes such as QuickDASH (52.1%), FABQ-PA (32.2%), and WPAI activity (65.4%). Disability recovery correlated with a reduction in FABQ-PA and surgery likelihood (76.1%). Meaningful reductions were also noted in mental health (67.0% in anxiety and 72.7% in depression), analgesic consumption (from 22.5% at baseline to 7.1% at program end), and productivity losses (68.2%).

4.2. Comparison with literature

There is no clear consensus on the management of WP, although the risks, costs, and limited benefits of surgery compared with nonsurgical therapies have led to a resurgence in the use of conservative measures, including exercise-based and psychological therapies.[2,70,71,80,92] As with other MSK conditions of the upper limb,[26,64,72,94] telerehabilitation is being explored as a valid alternative for WP conditions management.[8,9,36,53,84,87] Researchers are exploring telerehabilitation as an adjunctive approach to conventional therapy,[36,87] through synchronous video-based interactions, or as stand-alone therapy,[8,9,53,84] either by incorporating feedback systems in the intervention[8,9] or through haptic devices.[39,88]

The DCP herein described uses a more holistic approach to WP management, including a PT-monitored exercise program with real-time biofeedback and an educational component comprising CBT topics. Although the effect of exercise alone in wrist or hand pain is more frequently studied,[2,70,71] education and cognitive behavioral therapy are more commonly studied in combination with other interventions.[25,55,86] Cognitive behavioral therapy and patient education have demonstrated significant improvements in pain and disability,[76,97,102] and even strong evidence in helping return to work[28] in general chronic MSK, neck, or low back pain. However, education and CBT interventions alone seem to yield smaller effects compared with those achieved with other interventions, such as exercise, but evidence

Table 3

Outcome changes in patients with carpal tunnel syndrome: intent-to-treat approach (unconditional model).

Carpal tunnel syndrome					
Outcome mean (95% CI)	**N**	**Baseline**	**End of program**	**Mean change**	**% Change**
Pain level	50	4.18 (3.56; 4.89)	1.99 (1.09; 2.89)	2.19 (1.06; 3.33)	52.4
QuickDASH	50	25.15 (10.86; 29.44)	10.85 (5.61; 16.09)	14.30 (8.08; 20.52)	56.9
Surgery intent	50	20.07 (12.65; 27.49)	5.92 (0.32; 11.52)	14.15 (4.70; 23.59)	70.5
GAD-7	50	2.67 (1.59; 3.76)	1.28 (0.33; 2.23)	1.39 (0.30; 2.49)	52.2
PHQ-9	50	2.25 (1.30; 3.21)	0.78 (0.00; 1.79)	1.47 (0.31; 2.63)	65.4
FABQ-PA	49	10.08 (8.56; 11.61)	6.70 (3.90; 9.50)	3.38 (0.62; 6.14)	33.5
WPAI overall	43	17.42 (10.94; 23.91)	5.94 (0.60; 11.28)	11.48 (2.46; 20.51)	65.9
WPAI work	43	16.51 (10.50; 22.52)	6.06 (1.22; 10.90)	10.45 (2.35; 18.55)	63.3
WPAI activity	50	24.62 (17.69; 31.56)	7.04 (0.33; 13.76)	17.58 (8.32; 26.84)	77.4

FABQ-PA, fear-avoidance beliefs questionnaire for physical activity; GAD-7, generalized anxiety disorder 7-item scale; PHQ-9, patient health 9-item questionnaire; QuickDASH, quick disabilities of the arm, shoulder and hand questionnaire; WPAI, work productivity and activity impairment questionnaire.

supports that results can be maximized when integrated in multimodal approaches.[75,102]

The PT monitoring not only supported adjustments and quality of treatment but may also have enhanced patient motivation, accountability, and engagement. Although the study design did not enable the impact of each individual DCP component to be separately evaluated on the observed outcomes, important insights can be gleaned regarding feasibility, engagement, and overall improvement. Of note, enrollment occurred during the COVID-19 pandemic, when social distancing was a required practice. One big advantage of this intervention relates to its accessibility because all aspects of this DCP are delivered remotely, which in the particular case of this study, actually favored enrollment because all clinics were closed and off-limits to patients. The intervention completion rate (78.8%) was high and within the range reported by other telerehabilitation interventions (55.8% - 100%).[8,9,53,84,87] Higher completion rates have been reported only in small cohort studies and studies with shorter treatment periods. Engagement was very high, particularly in the first 4 weeks and for completers, where the average number of sessions performed matched the number recommended. This is important because it is well-established that patient adherence is paramount for recovery.[5,44,60]

Regarding health-related and productivity-related outcomes, reductions were observed across different domains. Wrist and hand pain–focused telerehabilitation studies are still scarce, and those that have been published used myriad different outcomes which limits direct comparison with our intervention. Blanquero et al. conducted 2 RCTs with cohorts of patients with wrist injuries[9] and CTS[8] and reported significantly higher pain and disability reductions after telerehabilitation compared with controls, with recoveries of 21.7% to 35.7% for pain and 46.6% to 49.0% for disability (QuickDASH). In this study, greater pain and disability changes were observed, considering both the entire cohort (51.3% and 52.1%, respectively) and the CTS subgroup (52.4% and 56.9%, respectively). Within the CTS subgroup, several RCTs have investigated the efficacy of different in-person conservative therapies, reporting pain reductions ranging between 15.8% and 32.4% and disability improvements between 5.9% and 20%.[6,40,43] This range may reflect variability in both the length and the components of the interventions, with some including an educational component. This is supported by evidence showing that education reinforces a patient's ability to cope with their condition, diminishing catastrophizing and kinesiophobia.[56,95]

In this study, we observed marked improvements for both FAB and mental health (32.2% for FABQ-PA, 67.0% for anxiety, and 72.7% for depression). The impact of these mental health domains is underexplored for WP, with reported improvements varying between 2% and 21.9% in mental health scales after conservative rehabilitation programs composed by exercise or exercise and education, without a component specifically dedicated on mental health.[40,43,53] Nevertheless, considering that high psychological stress is a known risk factor for WP[31] and the strong evidence supporting a biopsychosocial framework in the management of other MSK pain conditions, there seems to be a need to further study these components.[35,45,56]

Despite guidelines favoring conservative treatment, many still consider surgical intervention a first-line approach. Surgery may provide good short-term results, but long-term outcomes may not be clinically different from conservative approaches.[11,48,80,93] Moreover, surgical interventions may result in significant complications in some people, including nerve damage and worsening pain.[93] In this study, we observed a marked reduction in the intention to undergo surgery both in the entire cohort (78.1%) and in the CTS subgroup (70.5%), which further reinforces the recommendation to first try conservative treatment. These reductions are also in line with studies whereby exercise significantly reduced conversion to surgery.[55,78] Regarding medication consumption, a small proportion of participants reported analgesics use, less than the previously reported for hand osteoarthritis[37] or other chronic musculoskeletal pain conditions.[66] The reason for this is not clear; however, the cohort in this study included both acute (36.5%) and chronic (63.5%) conditions, which might partially explain the observed difference.

Considering our findings and the results of previous studies, the high reductions in productivity impairment both in the entire cohort (68.2%) and in the CTS subgroup (65.9%) are not surprising because improvements in pain and disability are expected to substantially affect leisure and work activities. This is important because WP is associated with greater productivity decrements than pain involving other anatomical regions.[4,77,90]

Female patients are consistently more affected with wrist conditions,[29,59] being 3 times more likely to have CTS than men[59,99] and having a poorer prognosis.[31,54,96] Our cohort had 60% female participants, who reported greater levels of pain, disability, and all WPAI domains than male participants at baseline. Contrary to previous reports,[31,54,96] at the end of the program, female participants attained similar outcomes to men in all domains.

4.3. Strengths and limitations

This study has several strengths, namely the novelty of the approach, which combined both camera-based and IMU-based motion capture technology (depending on exercise type) to provide real-time biofeedback during exercise execution. To the best of our knowledge, this is the first device which combines both technologies for this purpose. In addition, this DCP included not only a PT-monitored exercise program, delivered through a technological platform, but also educational and CBT components and was therefore structured within a biopsychosocial framework.[35,45,56] The digital nature of the program improves accessibility and convenience which, together with regular communication with the PT, promotes high adherence, which is known to translate into improved clinical outcomes.[44] Other strengths include the large sample size containing balanced female and male participation, as well as the broad set of secondary outcome measures evaluated.[7,33,51,69,82,83]

The major limitation is the lack of a control group. Considering the real-world context of the study, the most obvious control group would be "wait-listed patients," which would not simulate clinical practice and may not be ethical. Still, taken together, the aspects reported herein on engagement and observed outcomes will help guide future RCT comparing the DCP against in-person intervention. Other limitations include failure to stratify the impact of each DCP component and the lack of long-term outcomes to assess the persistence of results and relapse rates.

5. Conclusions

This multimodal DCP was able to foster high engagement and completion rates, which translated into clinically meaningful improvements in all outcomes. Significant reductions in pain, disability, analgesic usage, mental health, and surgery intent were observed, which in turn resulted in meaningful improvement in productivity. These results are in line with the literature, demonstrating that management of WP is possible through a remote DCP, thus eliminating barriers to access. Future RCTs comparing the DCP with conventional in-person PT or other telerehabilitation programs, including longer follow-up assessments, may provide further insights into recovery pathways and comparative effectiveness.

Disclosures

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Appendix A. Supplemental digital content

Supplemental digital content associated with this article can be found online at http://links.lww.com/PR9/A166.

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