Comparing In-Person, Standard Telehealth, and Remote Musculoskeletal Examination with a Novel Augmented Reality Exercise Game System: A Pilot Study

Richard Wu, Keerthana Chakka, Sara Belko, Ninad Khargonkar, Kevin Desai, Balakrishnan Prabhakaran, Thiru Annaswamy

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Abstract

Background: Current telemedicine technology is not optimized for conducting physical examinations. The Virtual Remote Tele-Physical Examination (VIRTEPEX) system, a novel proprietary technology platform which uses a Microsoft Kinect-based augmented reality game system to track motion and estimate force, has potential to assist with conducting asynchronous, remote musculoskeletal examination.

Objective: This pilot study evaluates the feasibility of the VIRTEPEX system for supplementing telehealth musculoskeletal strength assessments.

Methods: In this cross-sectional pilot study, 12 study participants with upper extremity pain and/or weakness underwent in-person, telehealth, VIRTEPEX, and composite (telehealth plus VIRTEPEX) strength evaluations for four upper extremity movements. Evaluators were blinded to one another's evaluations. The primary outcome was feasibility, as determined by participant study recruitment, completion, and safety. The secondary outcome was preliminary assessment of inter-rater agreements between in-person, telehealth, and VIRTEPEX strength assessments, plus kappa statistical calculations.

Results: This pilot study had an 80% recruitment rate, 100% completion rate, and 0 adverse events. In-person and telehealth evaluations had highest overall agreement (85.71%), greater than the agreements between in-person and VIRTEPEX (62.50%), in-person and composite (75%), and telehealth and VIRTEPEX evaluations (62.50%). However, for shoulder flexion, agreement between in-person and VIRTEPEX (78.57%, ?=0.571, 95% CI of 0.183 to 0.960), and also in-person and composite evaluations (78.57%, ?=0.571, 95% CI of 0.183 to 0.960), was greater than that for in-person and telehealth (71.43%, ?=0.429, 95% CI of -0.025 to 0.882).

Conclusions: This work demonstrates the feasibility of asynchronous VIRTEPEX examination and supports the potential for VIRTEPEX to supplement and add value to standard telehealth platforms. Further study, with additional development of VIRTEPEX and larger sample size for adequate power, is warranted.

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Keywords: physical examination, telemedicine, tele-physical assessment (Tele-PA), telerehabilitation, augmented reality (AR), game

Introduction

Telemedicine has seen increased utilization in recent years, especially during the COVID-19 pandemic [1]. An important advantage of telemedicine is flexibility, which has led to incorporation of telemedicine in various medical specialties, including radiology, psychiatry, dermatology, neurology, and cardiology [2]. Telemedicine can be useful for providing healthcare in difficult-to-reach locations, such as in the contexts of global health [3], rural/wilderness areas [4], disaster scenes [5], and outer space [6]. Many of these applications utilize video conferencing technology combined with peripheral examination devices, such as electronic stethoscopes, tele-opthalmoscopy cameras, video otoscopes, tele-dermatoscopes, digital endoscopes, electronic scales, smartphones, and wearables [2]. In the field of rehabilitation medicine, telecommunications technology has enabled telerehabilitation to facilitate remote patient encounters [7]. Examples of telerehabilitation applications include serving as a replacement for in-person visits for chronic lower back pain [8], as a method of remotely providing synchronous treatment interventions for musculoskeletal conditions [9], and as a means of implementing asynchronous rehabilitation following total knee replacement surgery [10].

However, existing telemedicine/telerehabilitation platforms have limitations. One limitation is that physical examinations are difficult to conduct through virtual platforms, as most telemedicine systems are limited to video/audio transmission. Thus, many physical examination components—including auscultation [11], palpation [2], and manual strength assessments [12]—often cannot easily be done through video/audio alone, and may require either another provider at the remote site to assist with physical examination [2], or a peripheral device to collect biometric data. In regard to musculoskeletal examinations, healthcare providers using existing telemedicine systems can attempt to remotely evaluate patients' range of motion and concentric/eccentric strength by asking patients to move a joint/extremity across its full range of motion, raise a limb against gravity, or lift objects of known weight [12]. However, this assessment is limited compared to in-person musculoskeletal examination, and may not always provide reliable information for a healthcare provider to perform a comprehensive tele-physical assessment (TelePA).

In recent years, emerging technologies have shown promise for improving reliability/accuracy of TelePA. Wearable biometric sensors can facilitate remote evaluation by transmitting spatiotemporal position, speed, acceleration, gait, force, and/or haptic data in real time [13-16]. Alternatively, virtual/augmented reality technologies can immerse patients in simulated environments [13] and enable them to gain body ownership in virtual settings [17], thereby leading to greater patient motivation/engagement and psychosocial benefits during telerehabilitation [18]. Some TelePA systems utilize motion-sensing 3D sensors, such as the Microsoft Kinect system [19], which is a portable, low-cost motion analysis system equipped with RGB+Depth (RGB-D) camera technology [20]. The Kinect system has previously been used for various applications to assess patient movement and function, including examining upper/lower extremity function [21], detecting patient walking [22], performing gait analysis [23], assessing balance [24], and monitoring Parkinson's disease patients' mobility [25].

This pilot study aims to expand the scope of telemedicine and telerehabilitation by assessing feasibility of the novel Virtual Remote Tele-Physical Examination (VIRTEPEX) system, which combines an augmented reality computer game environment with the Microsoft Kinect system to track motion and estimate force during gameplay [26]. VIRTEPEX can be operated asynchronously to evaluate motion/strength, and has potential to augment TelePA during or between telemedicine visits.

Methods

VIRTEPEX Game System

VIRTEPEX is a proprietary technology platform that uses the Microsoft Kinect (v2) RGB-D camera [20] and machine learning software [27]. Technical specifications of VIRTEPEX have been published previously [26]. VIRTEPEX utilizes non-invasive motion tracking and inverse dynamics to estimate forces for four joint movements: shoulder abduction, shoulder flexion, elbow flexion, and wrist extension. As part of the user experience, patients perform the four joint movements while playing an augmented reality bowling computer game (Figure 1), which was rendered using Unity™. For each joint movement completed, the patient's level of strength utilized determines the momentum of a virtual bowling ball. VIRTEPEX records/transmits force estimates for each joint movement to a healthcare provider, who can asynchronously assess the patient's strength. During asynchronous evaluation, the healthcare provider performs the same four joint movements through VIRTEPEX, and for each joint movement performed by both the patient and provider, VIRTEPEX synthesizes a comparative animation with two virtual bowling balls colliding into one another (Figure 2). In the animation, the momentum of one ball corresponds to the patient's strength for the joint movement, the momentum of the other corresponds to the provider's strength, and a virtual midline point marks the location where the balls would collide if both users applied equal strength; the amount of deviation between the balls' collision location and midline point can subjectively inform the provider as to the difference in strength between the provider and patient.

Figure 1. The simulated bowling computer game interface [26].

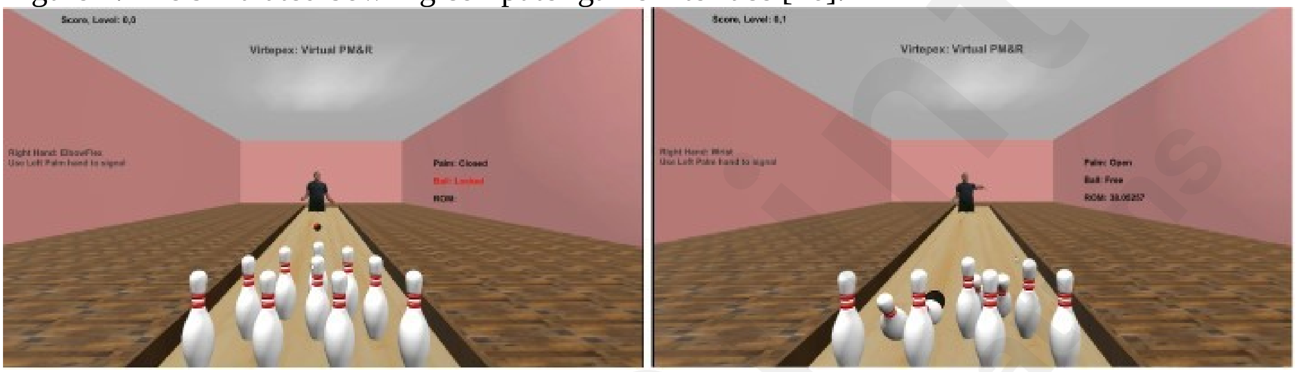
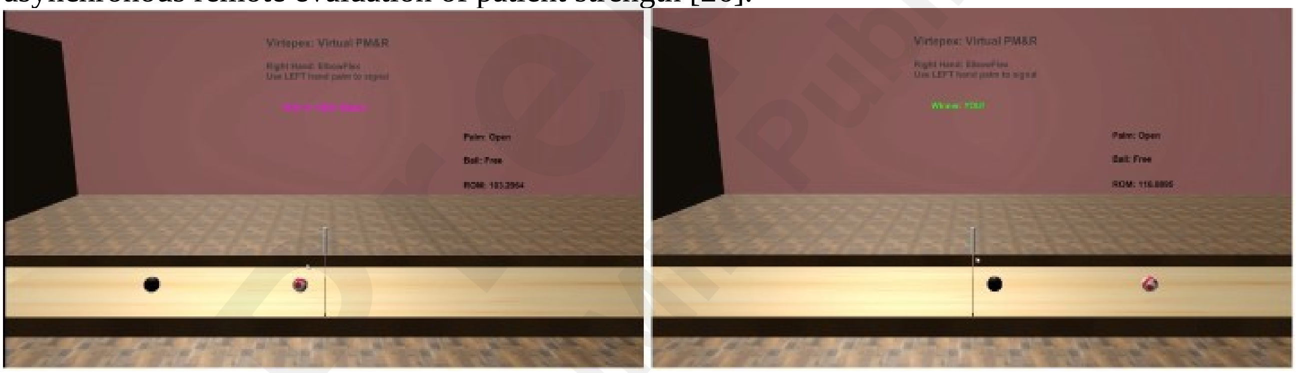


Figure 2. The simulated bowling ball collision animation viewed by the healthcare provider for asynchronous remote evaluation of patient strength [26].



Study Sample

This cross-sectional pilot study's sample included patients with impaired upper extremity movements due to any condition causing shoulder, elbow, and/or wrist pain/weakness, with the aim of evaluating movement strength regardless of underlying condition. Patients were recruited from a Veterans Affairs hospital's outpatient physical medicine and rehabilitation clinic. 15 patients initially agreed to participate, and three did not arrive to their scheduled research visit, leaving 12 remaining patients who were recruited for evaluation. Of these, 10 participants had unilateral upper extremity pain/weakness and were each only assessed for a single side, and the other two participants had bilateral upper extremity pain/weakness and had separate assessments done for each side. In total, this study included 14 evaluations, a number similar to that previously reported for comparable clinical studies of telerehabilitation technology [7]. Before formal evaluations, participants/evaluators received training on how to use VIRTEPEX and were allowed to interact with VIRTEPEX for some time to acclimate to the system.

Clinical Evaluation

Each participant's strength for four upper extremity movements—shoulder abduction, shoulder flexion, elbow flexion, and wrist extension—was assessed by three different evaluators, each of whom was blinded to the others' assessments. The first evaluator conducted an in-person examination, the second conducted a synchronous standard telehealth assessment, and the third conducted an asynchronous VIRTEPEX assessment. For each joint movement, the evaluator subjectively rated patient strength on a binary scale of normal or impaired. In addition, the telehealth and VIRTEPEX evaluations were incorporated together into a composite evaluation that aimed to represent how VIRTEPEX would be utilized to augment a typical telehealth assessment; the composite evaluation included data for wrist extension from telehealth assessment, and data for shoulder abduction, shoulder flexion, and elbow flexion from VIRTEPEX assessment. This composite evaluation was formulated by the evaluator using clinical judgement to decide between data from VIRTEPEX and telehealth assessments, a process similar to using clinical judgement to extrapolate information during in-person manual muscle testing—during evaluators' training on and interactions with VIRTEPEX, it was noted that wrist extension was the most difficult of the upper extremity movements to capture with the Kinect camera, and thus the composite evaluation defaulted to telehealth assessment data for all patients' wrist extension movements. Once evaluations were completed, data was deidentified.

Study Outcomes

Given this was a pilot study, our primary outcome was to assess for feasibility, which was evaluated based on participant recruitment, study completion, and safety. Recruitment rate was defined as the number of individuals who successfully enrolled and participated in this pilot study out of the total number of patients who were initially approached and agreed to participate in this study. Participants completed the study after undergoing each of the four upper extremity movement evaluations with each of the evaluators, as described above. Safety was determined from the number of adverse events during VIRTEPEX evaluation.

Our secondary outcome was preliminary assessment of inter-rater agreements, which were calculated for each of the four joint movements between the following: in-person and telehealth evaluations, in-person and VIRTEPEX evaluations, in-person and composite evaluations, and telehealth and VIRTEPEX evaluations. Raw percent agreement between two evaluators was calculated as the number of evaluations which agreed divided by total number of evaluations. Next, kappa statistics with 95% confidence intervals (CI) were calculated in Microsoft Excel for each joint movement to further quantify agreement between in-person and telehealth evaluations, in-person and VIRTEPEX evaluations, in-person and composite evaluations, and telehealth and VIRTEPEX evaluations. Kappa statistics were categorized on the following scale utilized in previous literature [28]: kappa values of 0.81 to 1.00 were considered as "almost perfect," 0.61 to 0.80 were considered as "excellent agreement," 0.41 to 0.60 as "moderate agreement," 0.21 to 0.41 as "fair agreement," 0.0 to 0.20 as "slight agreement," and <0.00 as "no agreement." Finally, overall raw percent agreement across all joint movements was calculated for each participant.

Research Consent

This study was approved by our institutional research ethics committee (Institutional Review Board). All participants provided written informed consent.

Results

User Statistics

Among 15 patients who were initially approached and agreed to participate in this study, 12 participated in evaluation and three did not arrive to their scheduled visit. As two participants had bilateral upper extremity deficits and were separately evaluated for each side, there were 14 total completed evaluations. Study recruitment rate was 80%, with 100% of the 12 participants completing the study, and 0% reporting adverse events.

Evaluation Outcomes

In-Person Versus Telehealth

Overall raw agreements between individual joint movements ranged from 71.43% to 100.00% (85.71% for shoulder abduction, 71.43% for shoulder flexion, 100.00% for elbow flexion, and 85.71% for wrist extension). Kappa values exhibited moderate to almost perfect agreement, ranging from 0.429 to 1.000 (substantial agreement with κ = 0.720, 95% CI of 0.375 – 1.000 for shoulder abduction; moderate agreement with κ = 0.429, 95% CI of -0.025 – 0.882 for shoulder flexion; almost perfect agreement with κ = 1.000, 95% CI of 1.000 – 1.000 for elbow flexion, and moderate agreement with κ = 0.440, 95% CI of -0.155 – 1.000 for wrist extension). Based on kappa values, the greatest agreement was for elbow flexion (almost perfect agreement with 100.00% raw agreement, κ = 1.000, 95% CI of 1.000 – 1.000), and least agreement for shoulder flexion (moderate agreement with 71.43% raw agreement, κ = 0.429, 95% CI of -0.025 – 0.882). Overall percent agreement was 85.71%, with percent agreement per participant varying from 50.00% to 100.00%.

Table 1. Raw percent agreements, kappa statistics, and confidence intervals (CI) for in-person versus telehealth evaluations. A = "Agree," D = "Disagree."

In-Person/ Telehealth	Joint Movement	Shoulder Abduction	Shoulder Flexion	Elbow Flexion	Wrist Extension	Agreement
Research Evaluation #	1	A	A	A	A	100%
	2	D	A	A	A	75%
	3	A	A	A	A	100%
	4	A	A	A	A	100%
	5	D	D	A	A	50%
	6	A	D	A	D	50%
	7	A	A	A	A	100%
	8	A	D	A	A	75%
	9	A	A	A	A	100%
	10	A	A	A	D	75%
	11	A	A	A	A	100%
	12	A	A	A	A	100%
	13	A	A	A	A	100%
	14	A	D	A	A	75%
	Agreement	85.71%	71.43%	100.00%	85.71%	85.71%
	Kappa	κ = 0.720	κ = 0.429	κ = 1.000	κ = 0.440	

	95% CI	0.375 to 1.000	-0.025 to 0.882	1.000 to 1.000	-0.155 to 1.000	

In-Person Versus VIRTEPEX

Overall raw agreements between individual joint movements ranged from 35.71% to 78.57% (57.14% for shoulder abduction, 78.57% for shoulder flexion, 78.57% for elbow flexion, and 35.71% for wrist extension). Kappa values exhibited slight to moderate agreement, ranging from κ = 0.060 to κ = 0.571 (fair agreement with κ = 0.222, 95% CI of -0.073 – 0.518 for shoulder abduction; moderate agreement with κ = 0.571, 95% CI of 0.183 – 0.960 for shoulder flexion; fair agreement with κ = 0.276, 95% CI of -0.332 – 0.883 for elbow flexion; and slight agreement with κ = 0.060, 95% CI of -0.065 – 0.185 for wrist extension). Based on kappa values, the greatest agreement was for shoulder flexion (moderate agreement with 78.57% raw agreement, κ = 0.571, 95% CI of 0.183 – 0.960), and least agreement for wrist extension (slight agreement with 35.71% raw agreement, κ = 0.060, 95% CI of -0.065 – 0.185). Overall percent agreement was 62.50%, with percent agreement per participant varying from 50.00% to 75.00%.

Table 2. Raw percent agreements, kappa statistics, and confidence intervals (CI) for in-person versus VIRTEPEX evaluations. A = "Agree," D = "Disagree."

In-Person/ VIRTEPEX	Joint Move-ment	Shoulder Abduction	Shoulder Flexion	Elbow Flexion	Wrist Extension	Agree-ment
Research Evaluation #	1	D	A	A	A	75%
	2	D	A	A	D	50%
	3	A	A	A	D	75%
	4	A	D	A	A	75%
	5	D	D	A	A	50%
	6	D	A	D	A	50%
	7	A	D	A	D	50%
	8	D	A	A	A	75%
	9	A	A	D	D	50%
	10	A	A	A	D	75%
	11	A	A	A	D	75%
	12	A	A	A	D	75%
	13	A	A	D	D	50%
	14	D	A	A	D	50%
	Agree-ment	57.14%	78.57%	78.57%	35.71%	62.50%
	Kappa	κ = 0.222	κ = 0.571	κ = 0.276	κ = 0.060	
	95% CI	-0.073 to 0.518	0.183 to 0.960	-0.332 to 0.883	-0.065 to 0.185	

In-Person Versus Composite Evaluations

Overall raw agreements between individual joint movements ranged from 57.14% to 85.71% (57.14% for shoulder abduction, 78.57% for shoulder flexion, 78.57% for elbow flexion, and 85.71% for wrist extension). Kappa values exhibited fair to moderate agreement, ranging from κ = 0.222 to κ = 0.571 (fair agreement with κ = 0.222, 95% CI of -0.073 – 0.518 for shoulder abduction; moderate agreement with κ = 0.571, 95% CI of 0.183 – 0.960 for shoulder flexion; fair agreement with κ =

0.276, 95% CI of -0.332 – 0.883 for elbow flexion; and moderate agreement with κ = 0.440, 95% CI of -0.155 – 1.000 for wrist extension). Based on kappa values, the greatest agreement was for shoulder flexion (moderate agreement with 78.57% raw agreement, κ = 0.571, 95% CI of 0.183 – 0.960), and least agreement for shoulder abduction (fair agreement with 57.14% raw agreement, κ = 0.222, 95% CI of -0.073 – 0.518). Overall percent agreement was 75.00%, with percent agreement per participant varying from 25.00% to 100.00%.

Table 3. Raw percent agreements, kappa statistics, and confidence intervals (CI) for in-person versus composite evaluations. A = “Agree,” D = “Disagree.”

In-Person/ Composite	Joint Movement	Shoulder Abduction	Shoulder Flexion	Elbow Flexion	Wrist Extension	Agreement
Research Evaluation #	1	D	A	A	A	75%
	2	D	A	A	A	75%
	3	A	A	A	A	100%
	4	A	D	A	A	75%
	5	D	D	A	A	50%
	6	D	A	D	D	25%
	7	A	D	A	A	75%
	8	D	A	A	A	75%
	9	A	A	D	A	75%
	10	A	A	A	D	75%
	11	A	A	A	A	100%
	12	A	A	A	A	100%
	13	A	A	D	A	75%
	14	D	A	A	A	75%
	Agreement	57.14%	78.57%	78.57%	85.71%	75%
	Kappa	κ = 0.222	κ = 0.571	κ = 0.276	κ = 0.440	
	95% CI	-0.073 to 0.518	0.183 to 0.960	-0.332 to 0.883	-0.155 to 1.000	

Telehealth Versus VIRTEPEX

Overall raw agreements between individual joint movements ranged from 35.71% to 78.57% (71.43% for shoulder abduction, 64.29% for shoulder flexion, 78.57% for elbow flexion, and 35.71% for wrist extension). Kappa values exhibited poor to fair agreement, ranging from κ = -0.033 to κ = 0.364 (fair agreement with κ = 0.364, 95% CI of -0.043 – 0.770 for shoulder abduction; slight agreement with κ = 0.186, 95% CI of -0.342 – 0.714 for shoulder flexion; fair agreement with κ = 0.276, 95% CI of -0.332 – 0.883 for elbow flexion; and poor agreement with κ = -0.033, 95% CI of -0.356 – 0.291 for wrist extension). Based on kappa values, the greatest agreement was for shoulder abduction (fair agreement with 71.43% raw agreement, κ = 0.364, 95% CI of -0.043 – 0.770), and least agreement for wrist extension (poor agreement with 35.71% raw agreement, κ = -0.033, 95% CI of -0.356 – 0.291). Overall percent agreement was 62.50%, with percent agreement per participant varying from 0.00% to 100.00%.

Table 4. Raw percent agreements, kappa statistics, and confidence intervals (CI) for telehealth versus VIRTEPEX evaluations. A = “Agree,” D = “Disagree.”

Telehealth/	Joint	Shoulder	Shoulder	Elbow	Wrist	

VIRTEPEX	Move-ment	Abduction	Flexion	Flexion	Extension	Agree-ment
Research Evaluation #	1	D	A	A	A	75%
	2	A	A	A	D	75%
	3	A	A	A	D	75%
	4	A	D	A	A	75%
	5	A	A	A	A	100%
	6	D	D	D	D	0%
	7	A	D	A	D	50%
	8	D	D	A	A	50%
	9	A	A	D	D	50%
	10	A	A	A	A	100%
	11	A	A	A	D	75%
	12	A	A	A	D	75%
	13	A	A	D	D	50%
	14	D	D	A	D	25%
	Agree-ment	71.43%	64.29%	78.57%	35.71%	62.50%
	Kappa	κ = 0.364	κ = 0.186	κ = 0.276	κ = -0.033	
	95% CI	-0.043 to 0.770	-0.342 to 0.714	-0.332 to 0.883	-0.356 to 0.291	

Discussion

Principal Results

This pilot study suggests that using VIRTEPEX to supplement telehealth strength assessment is feasible and safe. Further, VIRTEPEX has sufficiently acceptable levels of inter-rater agreement with in-person examination to warrant further evaluation for clinical use.

The inclusion of the composite assessment in this analysis is meant to illustrate how VIRTEPEX could be integrated into an existing clinical workflow. VIRTEPEX enables asynchronous collection of strength assessment data. Data from VIRTEPEX can help inform subsequent synchronous telehealth examinations, which could be performed more efficiently by focusing on movements noted to have deficits on VIRTEPEX. In a clinical implementation scenario, the provider would utilize clinical judgment to create a comprehensive assessment based on datapoints from different examination platforms. The composite evaluation in this study aims to represent this process and evaluate the utility of VIRTEPEX being employed in this manner; the results from this study suggest that VIRTEPEX has potential to augment remote strength assessment.

Between telehealth, VIRTEPEX, and composite evaluations, telehealth evaluation had greatest percent overall raw agreement with in-person evaluation (85.71%). This was higher than raw percent agreements between in-person and VIRTEPEX evaluations (62.50%), in-person and composite evaluations (75.00%), and telehealth and VIRTEPEX evaluations (62.50%). Previous research on inter-rater reliability for upper extremity musculoskeletal examinations has shown a wide but comparable range of agreement values: one study demonstrated raw inter-rater agreement values from 66.67% – 98.9% between different evaluators who performed the same in-person upper extremity examinations [28], while another study comparing telemedicine-based shoulder examinations with in-person evaluations exhibited raw agreement values from 46.7% – 83.7% [29].

Statistically significant agreement was observed between in-person and telehealth evaluations for shoulder abduction and elbow flexion (substantial agreement with κ = 0.720, 95% CI of 0.375 – 1.000 for shoulder abduction; almost perfect agreement with κ = 1.000, 95% CI of 1.000 – 1.000 for elbow flexion), in-person and VIRTEPEX evaluations for shoulder flexion (moderate agreement with κ = 0.571, 95% CI of 0.183 – 0.960), and in-person and composite evaluations for shoulder flexion (moderate agreement with κ = 0.571, 95% CI of 0.183 – 0.960). This suggests that while telehealth may have greater overall agreement with in-person evaluation and be better-suited for evaluating shoulder abduction and elbow flexion strength, VIRTEPEX and composite evaluations may be superior for remotely evaluating shoulder flexion strength.

Interestingly, none of the remote evaluation methods had statistically significant agreement with in-person evaluation for wrist extension strength, suggesting that further modification to both existing telehealth technology and VIRTEPEX may be needed to better remotely evaluate patients with wrist weakness/pain. Additionally, although telehealth and VIRTEPEX evaluations appeared to agree overall (62.50% raw agreement), none of the 95% CIs for the four joint movements' kappa values were statistically significant; while this could suggest that agreement between telehealth and VIRTEPEX evaluations may have been due to chance, it is also possible that this was because telehealth and VIRTEPEX evaluations each appeared to be better-suited for assessing different joint movements, thereby resulting in statistically significant differences in the data produced by these different evaluation mediums.

Limitations

This pilot study had several limitations. First, given that using VIRTEPEX requires reliable internet connection, this system would be less applicable for patients lacking internet access. Second, the sample size was small (14 evaluations total) and all participants were veterans, limiting generalizability to non-veteran populations. As this was a pilot study aimed at feasibility, the small sample size meant that this pilot study had less than 80% power (corresponding to around 22-30 evaluations), which would be needed to distinguish moderate inter-rater agreement (κ = 0.6) in a 2-sided test [30]; a future larger-scale fully-powered study would be needed to better quantify degree of agreement between in-person and telehealth evaluations, in-person and VIRTEPEX evaluations, in-person and composite evaluations, and telehealth and VIRTEPEX evaluations. Additionally, VIRTEPEX is currently still in development and is not yet available for clinical practice, as more work is needed to assess and improve the system's ease of use, cost-effectiveness, outcomes, and user satisfaction. Similarly, the subjective binary strength grading utilized for this study is not applied as a standard in clinical practice.

Future Directions

In this pilot study, VIRTEPEX was only used to remotely assess upper extremity movement strength. However, future development could allow VIRTEPEX to also remotely assess strength for joint movements in other areas of the body—such as hips, knees, ankles, torso, and neck—thereby helping facilitate a more comprehensive TelePA. Further work could potentially enable VIRTEPEX to evaluate multi-joint movements, gait, or balance. Additionally, given that the VIRTEPEX system did not evaluate for patient pain during movements, another potential feature to implement would be pain assessment.

Other potential future steps could help improve accessibility/appeal of VIRTEPEX. Although

VIRTEPEX is currently optimized for Microsoft Kinect, adapting VIRTEPEX to other devices could improve access for the wider population. Further, streamlining the user interface and incorporating more game design elements could simplify the user experience and increase user engagement during telerehabilitation. Finally, VIRTEPEX could be expanded beyond traditional telehealth settings to other clinical applications, such as remote physiological monitoring for patients needing recurrent physical assessments.

Conclusions

This study supports the feasibility of VIRTEPEX for supplementing telehealth and demonstrates VIRTEPEX is able to maintain moderate agreement with in-person evaluations. Notably, VIRTEPEX had greater agreement with in-person evaluation than telehealth did for shoulder flexion, suggesting that VIRTEPEX has potential to enhance existing telehealth technology. Further technological developments to VIRTEPEX, combined with more adequately powered studies, can better inform future evaluations of the effectiveness/accuracy of VIRTEPEX-supplemented TelePA.

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RW, KC, SB, NK, KD, BP, and TA contributed to the study conception and design. NK, KD, BP, and TA developed the VIRTEPEX system. RW, KC, and TA performed patient evaluations and data collection. RW performed data analysis. RW, KC, and SB drafted this manuscript. TA supervised this study and reviewed and edited this manuscript.

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Conflicts of Interest

None declared. Of note, VIRTEPEX is a proprietary device/product that has not yet been approved for use by the FDA for any purpose, is not labeled for use, and is still investigational.

Abbreviations

TelePA: tele-physical assessment
VIRTEPEX: Virtual Remote Tele-Physical Examination
RGB-D: RGB+Depth
CI: confidence interval

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