OPEN

Development and Preliminary Validity Study of a Modified Version of the Upper Extremity Fugl-Meyer Assessment for Use in Telerehabilitation

Carolina Carmona, PT, DPT, Jane E. Sullivan, PT, DHS, MS, Riegele Arceo, BA, Justin Drogos, PT, DPT, Sofie Besser, SPT, Susana Gutierrez, SPT, MS, Zineyra Jeteric, SPT, James Wyman, SPT, and Jun Yao, PhD

Background/Purpose: The Upper Extremity Fugl-Meyer Assessment (UEFMA, maximum 66) is widely used in clinics and research studies to examine poststroke upper extremity (UE) impairment. This study aimed to develop and provide pilot data to support the validity of a remote version of the UEFMA to examine UE impairment after stroke through telerehabilitation.

Methods: Team members developed a remote version of the UEFMA for telerehabilitation (tUEFMA, maximum 44) using subscales II to IV and VII of the UEFMA. Twenty-two participants with moderate to severe arm impairment (UEFMA, median = 19) and chronic stroke (>1 year post) were evaluated using the UEFMA (face-to-face) and the tUEFMA (remotely). A prediction equation was used to identify the function to predict the UEFMA based on the tUEFMA. Intraclass correlation (ICC) was used to test the absolute agreement between the subscales included in the UEFMA and the tUEFMA, and between their 2 normalized total scores.

Results: A strong and significant agreement was found between the total scores of the UEFMA and the projected value based on the tUEFMA (ICC = 0.79, $P < 0.05$). The ICC test also reported a good agreement in subscales II to IV and a poor agreement in subscale VII between the UEFMA and the tUEFMA using a real-time video link.

Discussion and Conclusions: The study findings suggest that the tUEFMA is a promising tool to remotely examine UE impairment in individuals with chronic stroke and moderate to severe arm impairment. Future research should evaluate additional psychometric properties and clinical utility of the tUEFMA across stroke participants with a broad range of arm impairments.

Video Abstract available for more insights from the authors (see the Video, Supplemental Digital Content 1, available at: http://links.lww.com/JNPT/A441).

Key words: *Fugl-Meyer Assessment, outcome measures, stroke, telehealth, telerehabilitation*

(*JNPT* 2023;47: 208–216)

Department of Physical Therapy and Human Movement Sciences, Northwestern University, Chicago, Illinois (C.C,. J.E.S., R.A., J.D., S.B., S.G., Z.J., J.W., J.Y.); and Northwestern University Interdepartmental Neuroscience, Northwestern University, and Department of Biomedical Engineering, Northwestern University, Chicago, Illinois (J.Y.).

This work was supported by the NIH Grant R21HDO94073, clinical trials registration NCT03986216 and departmental fund of the Physical Therapy and Human Movement Sciences Department, Northwestern University.

Part of the data was submitted for a poster presentation to the Combined Meetings Session, 2023, of the American Association of Physical Therapy. However, we have not yet received any information regarding the abstract's acceptance.

C.C. is the primary designer of the protocol and the modified version of the instrument, collected all remote assessments and some of the face-to-face assessments, contributed to data processing and interpretation and was the primary author of the article. J.E.S. helped design the protocol, develop the instrument's modified version, and participated in manuscript writing. R.A. coordinated recruitment and data storage and assisted with manuscript editing. J.D. helped develop the instrument's modified version and participated in face-to-face data collection and manuscript editing. J.Y. contributed to designing the protocol, data processing, interpretation, and manuscript writing. S.B., S.G., Z.J., and J.W. assisted with the literature review.

This study was carried out in accordance with the recommendations of Northwestern University, institutional review board with written informed consent from all subjects. All subjects gave written informed consent in accordance with the Declaration of Helsinki.

ClinicalTrials.gov registration numbers: NCT03986216, NCT04077073.

The authors declare no conflict of interest.

Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (www.jnpt.org).

This is an open-access article distributed under the terms of the Creative Commons Attribution-Non Commercial-No Derivatives License 4.0 (CCBY-NC-ND), where it is permissible to download and share the work provided it is properly cited. The work cannot be changed in any way or used commercially without permission from the journal.

Correspondence: Carolina Carmona, PT, DPT, Department of Physical Therapy and Human Movement Sciences, Northwestern University, 645 N Michigan Ave, Ste 1100, Chicago, IL, 60611 (ccarmona@northwestern.edu)

Copyright © 2023 The Authors. Published byWolters Kluwer Health, Inc. on behalf of Academy of Neurologic Physical Therapy, APTA.

ISSN: 1557-0576/23/4704-0208
DOI: 10.1097/NPT.0000000000000447

INTRODUCTION

Annually, more than 795 000 people in the United States experience a stroke.[1] After stroke, many individuals contend with motor impairments that limit the ability to use their arms, and negatively impact quality of life.[2,3] Up to 57% of individuals with stroke have limited access to rehabilitation services after hospital discharge.[4-6] Access to services, adequate transportation,[7] timely initiation of therapy, intensity, and appropriate frequency of treatment are critical elements for arm functional recovery and prevention of functional

decline,[8] especially for those with moderate to severe impairment. Telerehabilitation offers a potential solution that may increase access and continuity of rehabilitation services, particularly in rural and underserved areas[9]; for those with limited access to health care facilities and transportation[7]; and/or in situations where face-to-face care poses risks.[10]

While home-based interventions for arm recovery have been studied for years, outcome measures for use in telerehabilitation are not currently well-developed or studied. A limited number of studies have examined telerehabilitation/remote diagnosis of acute stroke severity and reported comparable results to face-to-face examinations.[11-13] Several outcome measures have been modified to facilitate remote assessment.[10,11,14] However, few studies have evaluated remote arm examination post-stroke.[15-19] Several remote examination studies utilized technology and robotic systems, which assess the arm through gaming,[20,21] wide-angle webcams, and desktop robot devices,[16] sensors and mobile applications,[22] and various technological platforms.[23] Specifically, one study examined the reliability of the Upper Extremity Fugl-Meyer Assessment (UEFMA) by comparing direct observation versus recorded video observation and suggested the video approach can reliably assess arm impairment.[24] A limitation of this approach is that the video-recording was done in the clinic rather than remotely. Similarly, a UEFMA assessment based on wearable sensor data[17] has shown promising results and could provide a quantitative approach for remote assessment. Barriers to implementing wearable sensors include access to technology, technology readiness, consumer technology literacy, and cost.[25] These barriers may be particularly seen in rural or underserved areas.[16,26]

Several recent reviews found comparable outcomes between face-to-face and remote interventions post-stroke, including improvements in upper extremity impairment and function.[9,27,28] Although rarely explicitly described in telerehabilitation studies, generally, participants appear to have undergone assessments face-to-face, rather than remotely via telehealth. All aspects of the episode of care should be available remotely to fully realize the benefits of telerehabilitation. Brito and colleagues[29] reviewed measurement tools used in the telerehabilitation of individuals with neurologic conditions, including 20 tools for stroke. While 8 tools were recommended, none targeted arm function post-stroke. Importantly, no tool reviewed was found to have published data on relevant psychometric properties and clinical utility.[29]

In this preliminary validity study, we targeted the examination of upper extremity impairment in those with moderate to severe stroke. The Upper Extremity Subscale of the Fugl-Meyer Assessment (UEFMA)[30-32] is an outcome measure widely used in a face-to-face format in clinical and research settings to evaluate the presence and severity of arm impairment and motor recovery post-stroke.[8,33] This instrument has been reported to be associated with corticospinal track integrity and prognosis for arm recovery.[34,35] The UEFMA has published validity[36] and interrater and intrarater reliability data[30] in stroke, making it a highly recommended instrument in clinical practice[37] in acute[38] and chronic stages following stroke.[36,39] Additionally, it is part of the recommended core outcome dataset for stroke recovery trials by the Stroke Recovery and Rehabilitation Roundtables.[40] The test items of the UEFMA are scored on a 3-point ordinal scale (0-2) used to rate voluntary arm and hand movement.[31,32] This instrument requires minimal equipment (household items), and a standardized training program is available to ensure reliable administration for clinicians and researchers.[41] Due to its feasibility, psychometric rigor, professional association recommendations, and frequency of use in stroke research,[42,43] we selected the UEFMA for remote use consideration. The purpose of this pilot study was to examine the preliminary validity of the Telerehabilitation Upper Extremity Fugl-Meyer Assessment (tUEFMA) when administered remotely, in a real-time/synchronous video format for individuals with chronic stroke and moderate to severe arm impairment.

METHODS

Outcome Measure Development

The UEFMA (original instrument) was used to assess arm impairment during face-to-face assessments. Three team members with more than 16 years of research experience with individuals with stroke developed the telerehabilitation version of the UEFMA (tUEFMA) by selecting items from the original instrument that were feasible for remote administration and met the following requirements: (1) could be performed independently by the person with stroke (positioning assistance or support could be provided with contralateral arm), (2) could be done safely, (3) required minimal position changes, (4) allowed the rater to visualize the entire arm, and (5) captured motion reliably in real time.

Based on this criterion, subscales I and V [Reflexes] of the UEFMA were removed because the assessment of reflexes requires the physical presence of a trained evaluator and thus cannot be completed remotely without assistance. Previous studies on dimensionality and construct validity of the UEFMA reported that eliminating the reflex items did not significantly alter scores for the impairment level or affect the instrument's motor construct.[43] Subscale VI [Wrist] was removed since 2 items potentially required manual stabilization from the examiner. Subscale VIII [Coordination/Speed] was removed because it involves timed items that have been shown to be problematic when examined via a video link.[10] In the tUEFMA, we further implemented modifications in the procedure for subscales III [Active Movement Mixing Synergies] and VII [Hand] since study participants had to use their less affected arm to support or stabilize their affected arm in the test position. Although the scoring was modified, efforts were made to preserve the testing and scoring criteria as much as possible with the original instrument. Table 1 provides the details on the subscales and items included, excluded, and modified in the tUEFMA. The total score for the tUEFMA (44) was compared with the UEFMA (66). The research team developed a script to optimize reliability (see Supplemental Digital Content 2, available at: http://links.lww.com/JNPT/A446).

Participants

For this study, we enrolled 22 participants (5 female, 16 male), mean age of 62.05 years (SD 9.51), and

© 2023 The Authors. Published by Wolters Kluwer Health, Inc. on behalf of Academy of Neurologic Physical Therapy, APTA

Table 1. tUEFMA: Subscore/Item Selection and Testing and Scoring Modification[a]

Subscore/Item	Maximum Score	Included	Comments
I and V: Reflexes	*4*	*No*	They cannot be completed without a trained clinician. Based on previous research, eliminating the reflex items does not significantly alter scores for the impairment level, or affect the construct of the instrument.[39]
II: Active Movement (Within Synergy)	*18*	*Yes*	No modifications made.
III: Active Movement (Mixing Synergies)	*6*	*Yes*	Modification for the item assessing pronation/supination with elbow flexion at 90º: 1. The participant must begin with the arm at their side with 0º of abduction, neutral internal/external rotation, and 90º of elbow flexion. If this is not possible, support is given just proximal to the elbow to stabilize the humerus against the torso using the less affected arm. Shoulder rotation and elbow flexion cannot be assisted. 2. Scoring: • *2* = arm position does not change, and pronation/supination is equal to or greater than the less affected arm. • *1* = if pronation/supination is possible with arm supported in the correct position (using less affected arm). • *0* = Participant cannot achieve the testing position even with support provided proximal to the elbow using the less affected arm OR elbow flexion/extension, shoulder abduction, internal/external rotation occurs at the onset of pronation/supination.
IV: Active Movement	*6*	*Yes*	Modification for the item assessing pronation/supination with elbow at 0° and shoulder between 30° and 90° of flexion. 1. Participants were instructed to support their arm just proximal to the elbow to stabilize the humerus in the correct position if they could not attain the initial position independently (the arm outstretched with the elbow fully extended to 0º).
VI: Wrist	*10*	*No*	Eliminated. Stabilization may be needed in more than one arm segment.
VII: Hand	*14*	*Yes*	Modification made for grasps A, B, C, D, E. 1. Support proximal to the elbow could not be provided using the less affected arm. 2. Participants were instructed to place the object using the less affected arm. 3. Scoring: • Score 0: Participants cannot achieve testing position independently. • Score 1: Participants able to attain standard position for all grasp testing independently, but, o Grasp A is weak. o Grasps B, C, D, E: the object cannot be kept in place against resistance. • Score 2: Testing position attained independently and o Grasp A: grasp can take relative resistance, o Grasps B, C, D, E: object placed in the affected arm is held well against a tug.
VIII: Coordination/Speed	*6*	*No*	Internet speed could interfere with video quality and appropriate scoring of task.

Abbreviations: tUEFMA, Telehealth Upper Extremity Fugl-Meyer Assessment (maximum score 44); UEFMA, Upper Extremity Fugl-Meyer Assessment (maximum score 66).
[a]Testing position: Participants in tall sitting position, using a chair without arms. Movement is compared between the affected and less/nonaffected arms.

mean time from stroke onset to first assessment of 11.90 years (SD 8.94; range 2.88-36.29 years). The demographics of participants are shown in Table 2. The Northwestern University Institutional Review Board approved this study. All procedures performed in the study were in accordance with the ethical standards of the institutional and the national research ethics committee, and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. All participants gave informed written consent.

Over a period of 2 years, participants were recruited from the clinical research registry hosted by Shirley Ryan Ability lab and the Department of Physical Therapy and Human Movement Sciences at Northwestern University, using the following inclusion/exclusion criteria. *Inclusion*: (1) more than 12 months post-stroke onset; (2) 18 to 80 years old; (3) unilateral arm motor impairment post-stroke; (4) moderate to severe arm impairment (UEFMA scores <40/66); (5) ability to follow a 3-step command; (6) availability to come to the laboratory for a face-to-face session; (7) access to and ability to use technology (real-time video, through phones, tablets, or computers); (8) ability to provide informed consent; (9) absence of motor impairment in the nonparetic arm; (10) absence of any inflammatory condition or pain in the arm or spine limiting motor testing. *Exclusion*: (1) moderate-severe hearing or vision impairment or aphasia; (2) moderate-severe cognitive impairment (Montreal Cognitive Assessment, score ≤ 23[44]); (3) any amputation in the paretic arm; (4) diagnosis of neurologic disorder other than stroke (Parkinson disease, multiple sclerosis, amyotrophic lateral sclerosis, traumatic brain injury, and peripheral neuropathies); (5) use of chemodenervation agents—botulinum toxin, Myobloc, Dysport (<3 months) or phenol/alcohol injections (<12 months) in the paretic arm.

 © 2023 The Authors. Published by Wolters Kluwer Health, Inc. on behalf of Academy of Neurologic Physical Therapy, APTA

Table 2. Demographics

Characteristics	Total n = 22
Age, mean (SD), y	61.50 (9.27)
Years since onset: mean (median, SD)	11.81 (10.02, 8.91)
Sex	
Female	5
Male	17
Ethnicity	
Hispanic	2
Non-Hispanic	19
Unknown or not reported	1
Race	
African American/Black	8
Asian	3
White	11
Side of hemiparesis	
Right	9
Left	13
UEFMA, range (median; IQR)	6-38 (19; 12-23.75)
Concordance[a]	
Concordant	9
Discordant	13

Abbreviations: IQR, interquartile range; UEFMA, Upper Extremity Fugl-Meyer Assessment (maximum score 66).

[a]Concordant: The paretic limb is the dominant limb. Discordant: The paretic limb is the nondominant limb.

Assessment, Scoring, and Examiners

Each participant was evaluated twice, once face-to-face with the UEFMA (maximum score 66) and once remotely with the tUEFMA (maximum score 44). The interval range between test evaluations was 1 to 46 weeks (median: 4 weeks); however, the between-test interval for 74% of participants was 1 to 8 weeks. Three examiners (A1, A2, and A3), all board-certified clinical specialists in neurologic physical therapy with more than 5 years of stroke research experience, conducted the examinations. All underwent training and standardization in the use of the outcome measures. A1 administered all the tUEFMA assessments on a video commercial platform (Zoom, WhatsApp, or Facetime) in real time (synchronous). Participants used their own available devices, including desktop computers, laptops, tablets, smartphones, and webcams.

At the beginning of the remote session, privacy and safety concerns (position, fall risks) were discussed. Additionally, camera position to best capture the triplanar motions of arms was addressed. For some participants, the equipment was adjusted during the session to better visualize their arms. During the face-to-face session the UEFMA was administered by 1 of the 3 examiners.

Data and Statistical Analysis

A Bland-Altman analysis was performed using SPSS Statistics (SPSS Inc, Chicago, Illinois) to assess the magnitude and direction of bias between the tUEFMA and the UEFMA. To facilitate the transition between the 2 measures and the clinical usage of the tUEFMA score, we projected the tUEFMA obtained in the remote session to the full score of the UEFMA by a linear function that best fits the 2 measures.

To evaluate the validity of the tUEFMA, we normalized the raw scores to their total scores (total scores: UEFMA = 66 vs tUEFMA = 44). We then used the intraclass correlation (ICC) test in R (The R Foundation for Statistical Computing, http://www.R-project.org) to test the absolute agreement between the subscales that were included in both the UEFMA and the tUEFMA (subscales II-IV and VII), and between the 2 normalized total scores from these 2 outcome measures. We used a 2-way random, single-measured, agreement model in R for all the ICC tests. ICC values less than 0.50 indicate a poor agreement; between 0.5 and 0.75, 0.75 and 0.9 indicate a moderate and good agreement, respectively, and greater than 0.9 indicates an excellent agreement.

RESULTS

In total, 44 test administrations were collected (2 per participant). There were no missing data sets. A Bland-Altman plot comparing the tUEFMA to the UEFMA reported one observation falling outside the limits of agreement (see Figure 1). The mean difference between the UEFMA and the tUEFMA was 7.18 (confidence interval = 4.85-9.50), with limits of agreement estimated to be $7.18 \pm (1.96 \times 5.2)$. Considering the difference in the maximum values of the tUEFMA (maximum = 44) and the UEFMA (maximum = 66), the mean difference at 7.8 was expected. Points fell both above and below the mean difference, indicating no consistent bias.

ICC test results are summarized in Table 3. As shown in this table, there was a significant ($P < 0.05$) and moderate to good agreement between subscales used in the tUEFMA and the UEFMA, except for subscale VII [Hand], which had a poor agreement between the 2 measures. The ICC test also showed a good agreement between the total of the subscales on both tests, and between the 2 normalized instruments. The tUEFMA predicted the UEFMA with a significant and good agreement.

The relative errors between the tUEFMA and UEFMA scores—(t value – real value)/real value—for each subscale II to IV (Active Movement Within Synergy, Active Movement Mixing Synergies, Active Movement With Little or No Synergy) and VII (Hand) are plotted in Figure 2. The scores obtained on tUEFMA subscales II (Active Movement Within Synergy), IV (Movement With Little or No Synergy), and VII (Hand) were, in general, smaller than those obtained on the UEFMA. The scores on subscale III (Active Movement Mixing Synergies) were relatively larger. Relatively smaller relative errors were found on subscale IV (Movement With Little or No Synergy). The ICC for this subscale was not high, likely due to the large number of participants (15 out of 22) that scored zero on this subscale (ie, the floor effect). The overall relative error from all subscales included in both tools was slightly negative, suggesting that scores from the tUEFMA subscales were smaller than those on the UEFMA subscales. The projection from the tUEFMA to the pUEFMA did not make the relative error larger ($P < 0.05$).

To facilitate the transition between the 2 measures, we projected the tUEFMA score obtained in the remote session to the full score of the UEFMA by a linear function that best

© 2023 The Authors. Published by Wolters Kluwer Health, Inc. on behalf of Academy of Neurologic Physical Therapy, APTA

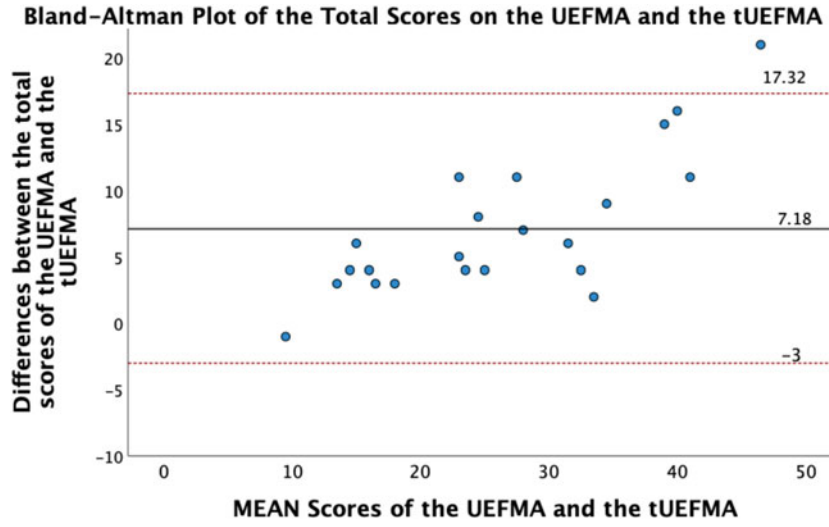

Figure 1. Bland-Altman plot compares the scores from 2 clinical outcome measures (ie, tUEFMA and UEFMA). The middle horizontal solid black line shows the bias (the mean of the difference between the total scores of the UEFMA and the tUEFMA), and the 2 dashed red lines are the lower limits (mean – 1.96 × SD) and the upper limits (mean + 1.96 × SD), respectively. tUEFMA, Telerehabilitation Upper Extremity Fugl-Meyer Assessment; UEFMA, Upper Extremity Fugl-Meyer Assessment. This figure is available in color online (www.jnpt.org).

Table 3. ICC Test Results[a]

UEFMA Subscales	II	III	IV	VII	Subtotal of Subscales II, III, IV, and VII	Normalized tUEFMA vs Normalized UEFMA (Total Scores)	pUEFMA vs UEFMA (Total Scores)
ICC (2)	0.648	0.819	0.664	0.371	0.849	0.798	0.796
F	5.25	9.9	4.86	2.16	13.8	8.77	8.46
Confidence interval (L/U)	0.317/0.837	0.616/0.92	0.347/0.845	−0.052/0.68	0.656/0.936	0.577/0.91	0.568/0.91

Abbreviations: ICC, intraclass correlation; L/U, lower/upper limit; pUEFMA, Projected Upper Extremity Fugl-Meyer Assessment (predicted value); tUEFMA, Telerehabilitation Upper Extremity Fugl-Meyer Assessment; UEFMA, Upper Extremity Fugl-Meyer Assessment.

[a]ICC test results using a single score, 2-way model, and agreement type. There was a significant ($P < 0.05$) and moderate to good agreement between subscales that were used in both the tUEFMA and the UEFMA even with modifications, except for subscale VII (hand function) with a poor agreement.

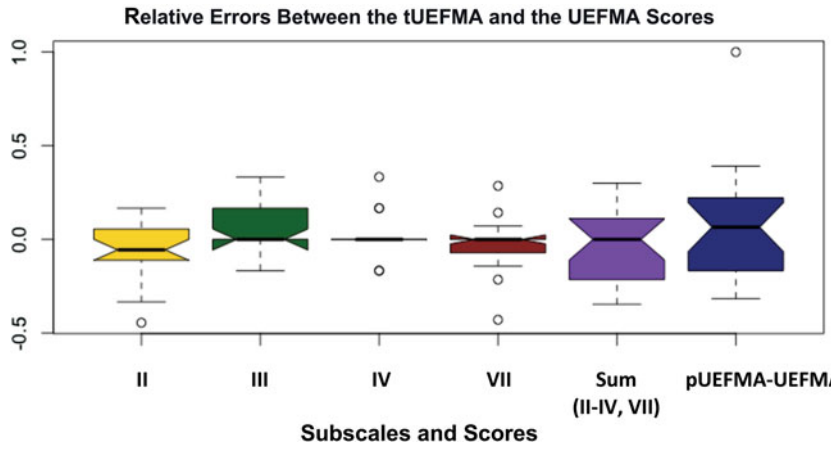

Figure 2. Errors between the tUEFMA and UEFMA scores in each of the subscales from II to IV and VII. Scores obtained in tUEFMA subscales II, IV, and VII were in general smaller than those obtained from the UEFMA, while the ones from subscale III were relatively larger. pUEFMA, Projected Upper Extremity Fugl-Meyer Assessment (predicted value); tUEFMA, Telerehabilitation Upper Extremity Fugl-Meyer Assessment; UEFMA, Upper Extremity Fugl-Meyer Assessment. This figure is available in color online (www.jnpt.org).

 © 2023 The Authors. Published by Wolters Kluwer Health, Inc. on behalf of Academy of Neurologic Physical Therapy, APTA

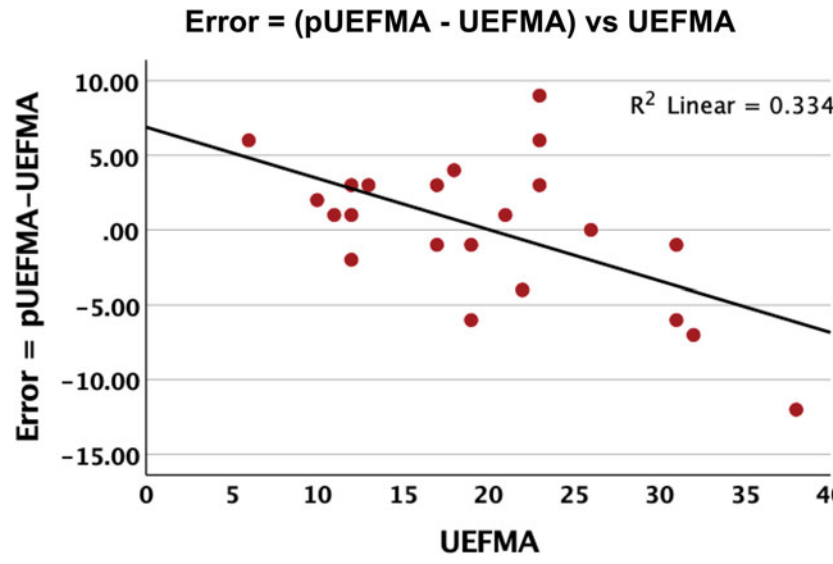

Figure 3. Linear regression showing the Error = (pUEFMA − UEFMA) Versus UEFMA. Positive errors mean the projected UEFMA is greater than expected and negative errors mean the projected UEFMA is lower than expected. pUEFMA, Projected Upper Extremity Fugl-Meyer Assessment (predicted value); UEFMA, Upper Extremity Fugl-Meyer Assessment. This figure is available in color online (www.jnpt.org).

fitted both measures. This resulted in the projected UEFMA (pUEFMA), that is, pUEFMA = 1.41× (tUEFMA) + 2.

To understand whether a participant's level of impairment impacts the score of the tUEFMA, we further examined the relationship between the measurement error (ie, pUEFMA − UEFMA) and the UEFMA. The regression data between the error (pUEFMA − UEFMA) and the UEFMA (Figure 3) showed a significant ($P < .005$) weak negative relationship between the impairment level and the error, suggesting that the tUEFMA performed better for the more severely impaired participants (UEFMA 10-20, mean absolute error = 2.75), and worse for individuals with more moderate impairment (UEFMA 21-40, mean absolute error = 4.9). Positive errors mean the pUEFMA is greater than expected and negative errors mean the pUEFMA is lower than expected.

DISCUSSION

This study examined the preliminary validity of the tUEFMA when administered remotely, in a real-time/synchronous video format for individuals with chronic stroke and moderate to severe arm impairment. We found a strong and significant agreement between the total scores of the UEFMA and the projected value based on the tUEFMA. The ICC test also reported a good agreement in subscales II to IV [Active Movement Within Synergy, Active Movement Mixing Synergies, and Active Movement With Little or No Synergy] and a poor agreement in subscale VII [Hand] between the UEFMA and the tUEFMA administered using a real-time video link.

The authors of a 2022 review discussed the paucity of information on remote examination in neurologic populations and recommended future studies consider both the clinical utility and psychometrics of developing tools[29] We conducted a pilot evaluation of the validity of a modified version of the UEFMA. Despite the time recommended for examiner training,[45] the tUEFMA is a cost-effective tool that does not require advanced technology, or additional software/hardware beyond that needed for a telerehabilitation encounter.[32,45] Although devices and technology may enhance measurement precision, these may be limited in poorly resourced settings.[46,47] The approach used in this pilot study requires basic technology (internet, camera, and phone/computer) that is currently accessible to 90% of the US population.[48-50]

This study supports the validity of the tUEFMA. Bland-Altman plots showed only one observation falling outside of the limits of agreement, with the points falling both above and below the mean difference, indicating no strong bias in one direction. In comparable subscales from the tUEFMA and the UEFMA, there were significant and good agreements in subscales II (Active Movement Within Synergy), III (Active Movement Mixing Synergies), and IV (Active Movement With Little to No Synergy) but poor agreements in subscale VII (Hand). The linear function, pUEFMA = 1.41 × (tUEFMA) + 2, may be used to provide an estimate of the poststroke arm impairment based on the tUEFMA when face-to-face examination is unattainable, with a significant and good agreement for individuals with chronic stroke and moderate to severe impairment. The prediction equation developed in this study will be examined in a future study, with a larger and independent sample.

We found a poor agreement between the tUEFMA and the UEFMA in subscale VII [Hand], which may be partially due to modifications implemented in the tUEFMA. During grasp items (A-E) participants were required to perform the test independently, without arm support. This may have impacted participants' ability to achieve the standard test position, to perform the task, or affected the examiner's scoring. These facts could have contributed to the lower agreement scores on this subscale.

© 2023 The Authors. Published by Wolters Kluwer Health, Inc. on behalf of Academy of Neurologic Physical Therapy, APTA

Regression results indicate that the tUEFMA performed better in subjects with more severe impairment (UEFMA 10-20, mean absolute error = 2.75) and worse in subjects with more moderate impairment (UEFMA 21-40, mean absolute error = 4.9). To accurately evaluate the impact of arm impairment on tUEFMA scores, test validity, and precision of predictions, future work will enroll a larger sample of subjects with stroke with a broader range of arm impairment and include individuals at different time points post-stroke.

Methodological Quality Assessment

The methodological quality of the present study was assessed using the consensus-based standards for the selection of health status measurement instruments (COSMIN).[51,52] We used the COSMIN content validity, and criterion validity 7 items to determine whether the results of the present study could be trusted. Twelve COSMIN items were scored on a 4-point rating scale (very good = 3, adequate = 2, doubtful = 1, or inadequate = 0, and N/A = not applicable). Three content validity items were rated excellent, and 2 adequate. Four criterion validity items were rated excellent, 2 adequate, and 1 not applicable. Therefore, the COSMIN rating was appropriate, and we believe the methodological quality of the pilot study can be considered adequate. A detailed COSMIN Checklist with scoring and explanations is included in Supplemental Digital Content 2 (available at: http://links.lww.com/JNPT/A446).

STUDY LIMITATIONS

The sample size in this preliminary study (n = 22) was small. While the COVID-19 pandemic, in part, prompted the study development, conducting the study during the pandemic impacted recruitment and contributed to the long time between remote and face-to-face testing sessions (1-46 weeks). However, the median interval between tests (4 weeks) is more closely aligned to typical clinical practice. For 73% of participants, the interval between tests was 1 to 8 weeks. This time frame may be somewhat offset by the chronicity of participants (mean = 11.81 years, SD 8.9). This level of chronicity suggests that our participants may have had a more stable level of motor impairment. Currently, we are planning to further explore the psychometrics of the tUEFMA with a larger sample size and a standardized, smaller between-test interval. Although recent reports suggest a trend of stroke incidence in younger adults,[53,54] the mean age of our participants was 62.05 years (SD 9.51), which is younger than what has been reported in other studies.

Factors such as participants' digital literacy, caregiver support, internet speed, and access to technology[55] may influence the success of a remote assessment during a telerehabilitation clinical encounter. We attempted to minimize these barriers by addressing camera set-up, platform use, and safety during the phone screening. We also discussed available Wi-Fi, networks, and free internet hotspots.[56] Despite this, some participants experienced difficulty setting up cameras or accessing sufficiently strong Wi-Fi signals, which may have influenced video quality. For some participants, equipment was adjusted during the remote session to better visualize their arms. Arm visibility was challenging, mainly when participants had limited mobility. Future changes in commercial devices for teleconferences will likely impact the development, utility, and reliability of telerehabilitation examination.

The current development of the tUEFMA emphasized cost-efficiency and feasibility of implementation, and thus excluded some subscales from the UEFMA. Future research should evaluate the full range of psychometrics of the tUEFMA. We plan a larger scale study, which would examine the question of whether the addition of subscale VIII [Coordination/Speed] and 3 items from subscale VI [Wrist]: wrist flexion/extension with elbow at 90°, wrist flexion/extension with elbow at 0,° and wrist circumduction will improve the overall agreement with the UEFMA.

One examiner (A1) performed all remote examinations, and 3 examiners (A1, A2, and A3) performed face-to-face tests. The fact that A1 conducted both face-to-face and remote examination may have introduced bias. The remote testing was always performed before the face-to-face session. This may also have biased the validity test results.

Despite our promising results, given the size of our sample and the inclusion of only moderate to severely impaired participants, we cannot yet generalize the findings across impairment levels. However, future research should still evaluate additional psychometric properties and clinical utility of the tUEFMA, in larger samples that include research participants with a broader range of clinical impairments and chronicity.

CONCLUSIONS

The findings of this preliminary validity study suggest that the tUEFMA is a promising outcome measure to remotely examine upper extremity motor function in individuals with chronic stroke and moderate to severe arm impairment.

CLINICAL RELEVANCE

Developing and validating clinical outcome measures for telerehabilitation is important to ensure continuity of care across settings, increase access to care, and extend research participation when face-to-face engagements are challenging or are not possible. Implementing clinical assessments for telerehabilitation may also improve the quality of care, help track impairment progress or decline, and positively impact health outcomes in individuals with stroke. Future studies should evaluate the cost-effectiveness and clinical utility of the tUEFMA in routine clinical practice. Examining barriers, facilitators and satisfaction, and user's training needs will drive further development, application, and delivery of telerehabilitation to individuals with stroke.

ACKNOWLEDGMENTS

We would like to acknowledge our participants for taking the time to engage in this study, as well as the clinicians who assisted in recruiting participants.

We also want to acknowledge Jimmy Jacinto, SPT, and Samuel Choi, SPT, for assisting with literature review, and Amanda Carlson, PT, DPT, for assisting with data collection.

 © 2023 The Authors. Published by Wolters Kluwer Health, Inc. on behalf of Academy of Neurologic Physical Therapy, APTA

REFERENCES

1. Tsao CW, Aday AW, Almarzooq ZI, et al. Heart disease and stroke statistics—2022 update: a report from the American Heart Association. *Circulation*. 2022;145(8):e153-e639. doi:10.1161/cir.0000000000001052.
2. Xie J, Wu EQ, Zheng ZJ, et al. Impact of stroke on health-related quality of life in the noninstitutionalized population in the United States. *Stroke*. 2006;37(10):2567-2572. doi:10.1161/01.Str.0000240506.34616.10.
3. Joundi RA, Adekanye J, Leung AA, et al. Health state utility values in people with stroke: a systematic review and meta-analysis. *J Am Heart Assoc*. 2022;11(13):e024296. doi:10.1161/jaha.121.024296.
4. Ayala C, Fang J, Luncheon C, et al. Use of outpatient rehabilitation among adult stroke survivors—20 states and the District of Columbia, 2013, and four states, 2015. *MMWR Morb Mortal Wkly Rep*. 2018;67:575-578. https://www.cdc.gov/mmwr/volumes/67/wr/mm6720a2.htm?s_cid=mm6720a2_w.
5. Hall P, Williams D, Hickey A, et al. Access to rehabilitation at six months post stroke: a profile from the Action on Secondary Prevention Interventions and Rehabilitation in Stroke (ASPIRE-S) Study. *Cerebrovasc Dis*. 2016;42(3/4):247-254. doi:10.1159/000446080.
6. Owolabi MO, Thrift AG, Martins S, et al. The state of stroke services across the globe: report of World Stroke Organization–World Health Organization surveys. *Int J Stroke*. 2021;16(8):889-901. doi:10.1177/17474930211019568.
7. Syed ST, Gerber BS, Sharp LK. Traveling towards disease: transportation barriers to health care access. *J Community Health*. 2013;38(5):976-993. doi:10.1007/s10900-013-9681-1.
8. Stinear CM, Smith M-C, Byblow WD. Prediction tools for stroke rehabilitation. *Stroke*. 2019;50(11):3314-3322. doi:10.1161/STROKEAHA.119.025696.
9. Tchero H, Tabue Teguo M, Lannuzel A, Rusch E. Telerehabilitation for stroke survivors: systematic review and meta-analysis. *J Med Internet Res*. 2018;20(10):e10867. doi:10.2196/10867.
10. Peters S, Botero M, Evers A, et al. Development and feasibility of a modified Fugl-Meyer lower extremity assessment for telerehabilitation: a pilot study. *Pilot Feasibility Stud*. 2021;7(1):121. doi:10.1186/s40814-021-00862-8.
11. Barclay R, Miller PA, Pooyania S, Stratford P. Development of a telephone interview version of the Chedoke-McMaster Stroke Assessment Activity Inventory. *Physiother Can*. 2016;68(3):216-222. doi:10.3138/ptc.2015-44.
12. Gonzalez MA, Hanna N, Rodrigo ME, Satler LF, Waksman R. Reliability of prehospital real-time cellular video phone in assessing the simplified National Institutes of Health Stroke Scale in patients with acute stroke: a novel telemedicine technology. *Stroke*. 2011;42(6):1522-1527. doi:10.1161/strokeaha.110.600296.
13. Handschu R, Littmann R, Reulbach U, et al. Telemedicine in emergency evaluation of acute stroke: interrater agreement in remote video examination with a novel multimedia system. *Stroke*. 2003;34(12):2842-2846. doi:10.1161/01.Str.0000102043.70312.E9.
14. Palsbo SE, Dawson SJ, Savard L, Goldstein M, Heuser A. Televideo assessment using Functional Reach Test and European Stroke Scale. *J Rehabil Res Dev*. 2007;44(5):659-664. doi:10.1682/jrrd.2006.11.0144.
15. Yang C-l, Waterson S, Eng JJ. Implementation and evaluation of the virtual Graded Repetitive Arm Supplementary Program (GRASP) for individuals with stroke during the COVID-19 pandemic and beyond. *Phys Ther*. 2021;101(6):pzab083. doi:10.1093/ptj/pzab083.
16. Jones RB, Hubble S, Taylor L, et al. Technologies to support assessment of movement during video consultations: exploratory study. *JMIRx Med*. 2021;2(3):e30233. doi:10.2196/30233.
17. Yu L, Xiong D, Guo L, Wang J. A remote quantitative Fugl-Meyer assessment framework for stroke patients based on wearable sensor networks. *Comput Methods Programs Biomed*. 2016;128:100-110. doi:10.1016/j.cmpb.2016.02.012.
18. Avelino PR, Menezes KKP, Nascimento LR, et al. Validation of the telephone-based application of the ABILHAND for assessment of manual ability after stroke. *J Neurol Phys Ther*. 2020;44(4):256-260. doi:10.1097/npt.0000000000000326.
19. Pérez-Robledo F, Llamas-Ramos R, Llamas-Ramos I, Bermejo-Gil BM, Sánchez-González JL, Martín-Nogueras AM. Adaptación y viabilidad de la versión telemática de la escala Fugl Meyer para la evaluación de pacientes tras accidentes cerebrovasculares [Adaptation and feasibility of the online version of the Fugl Meyer scale for the assessment of patients following cerebrovascular accidents]. *Rev Neurol*. 2022;74(5):156-162. doi:10.33588/rn.7405.2021385.
20. Rodriguez-de-Pablo C, Perry JC, Cavallaro FI, Zabaleta H, Keller T. Development of computer games for assessment and training in post-stroke arm telerehabilitation. *Annu Int Conf IEEE Eng Med Biol Soc*. 2012;2012:4571-4574. doi:10.1109/embc.2012.6346984.
21. Rodriguez-de-Pablo C, Balasubramanian S, Savic A, Tomic TD, Konstantinovic L, Keller T. Validating ArmAssist Assessment as outcome measure in upper-limb post-stroke telerehabilitation. *Annu Int Conf IEEE Eng Med Biol Soc*. 2015;2015:4623-4626. doi:10.1109/embc.2015.7319424.
22. Fell N, True HH, Allen B, et al. Functional measurement post-stroke via mobile application and body-worn sensor technology. *Mhealth*. 2019;5:47. doi:10.21037/mhealth.2019.08.11.
23. Sobrepera MJ, Lee VG, Garg S, Mendonca R, Johnson MJ. Perceived usefulness of a social robot augmented telehealth platform by therapists in the United States. *IEEE Robot Autom Lett*. 2021;6(2):2946-2953. doi:10.1109/lra.2021.3062349.
24. Amano S, Umeji A, Uchita A, et al. Reliability of remote evaluation for the Fugl-Meyer assessment and the action research arm test in hemiparetic patients after stroke. *Top Stroke Rehabil*. 2018;25(6):432-437. doi:10.1080/10749357.2018.1481569.
25. Tumma A, Berzou S, Jaques K, Shah D, Smith AC, Thomas EE. Considerations for the implementation of a telestroke network: a systematic review. *J Stroke Cerebrovasc Dis*. 2022;31(1):106171. doi:10.1016/j.jstrokecerebrovasdis.2021.106171.
26. Anderson ER, Smith B, Ido M, Frankel M. Remote assessment of stroke using the iPhone 4. *J Stroke Cerebrovasc Dis*. 2013;22(4):340-344. doi:10.1016/j.jstrokecerebrovasdis.2011.09.013.
27. Laver KE, Adey-Wakeling Z, Crotty M, Lannin NA, George S, Sherrington C. Telerehabilitation services for stroke. *Cochrane Database Syst Rev*. 2020;1(1):CD010255. doi:10.1002/14651858.CD010255.pub3.
28. Appleby E, Gill ST, Hayes LK, Walker TL, Walsh M, Kumar S. Effectiveness of telerehabilitation in the management of adults with stroke: a systematic review. *PLoS One*. 2019;14(11):e0225150. doi:10.1371/journal.pone.0225150.
29. Brito SAF, Scianni AA, Peniche PDC, Faria CDCM. Measurement properties of outcome measures used in neurological telerehabilitation: a systematic review using COSMIN checklist. *Clin Rehabil*. 2023;37(3):415-435. doi:10.1177/02692155221129834.
30. Duncan PW, Propst M, Nelson SG. Reliability of the Fugl-Meyer assessment of sensorimotor recovery following cerebrovascular accident. *Phys Ther*. 1983;63(10):1606-1610.
31. Fugl-Meyer AR. Post-stroke hemiplegia assessment of physical properties. *Scand J Rehabil Med Suppl*. 1980;7:85-93.
32. Fugl-Meyer AR, Jääskö L, Leyman I, Olsson S, Steglind S. The post-stroke hemiplegic patient. 1. A method for evaluation of physical performance. *Scand J Rehabil Med*. 1975;7(1):13-31.
33. Lang CE, Bland MD, Bailey RR, Schaefer SY, Birkenmeier RL. Assessment of upper extremity impairment, function, and activity after stroke: foundations for clinical decision making. *J Hand Ther*. 2013;26(2):104-115. doi:10.1016/j.jht.2012.06.005.
34. Beninato M, Portney LG, Sullivan PE. Using the International Classification of Functioning, Disability and Health as a framework to examine the association between falls and clinical assessment tools in people with stroke. *Phys Ther*. 2009;89(8):816-825. doi:10.2522/ptj.20080160.
35. Stinear CM, Barber PA, Smale PR, Coxon JP, Fleming MK, Byblow WD. Functional potential in chronic stroke patients depends on corticospinal tract integrity. *Brain*. 2007;130(Pt 1):170-180. doi:10.1093/brain/awl333.
36. Page SJ, Hade E, Persch A. Psychometrics of the wrist stability and hand mobility subscales of the Fugl-Meyer assessment in moderately impaired stroke. *Phys Ther*. 2015;95(1):103-108. doi:10.2522/ptj.20130235.
37. Gor-García-Fogeda MD, Molina-Rueda F, Cuesta-Gómez A, Carratalá-Tejada M, Alguacil-Diego IM, Miangolarra-Page JC. Scales to assess gross motor function in stroke patients: a systematic review. *Arch Phys Med Rehabil*. 2014;95(6):1174-1183. doi:10.1016/j.apmr.2014.02.013.
38. Duncan P, Lai SM, Keighley J. Defining post-stroke recovery: implications for design and interpretation of drug trials. *Neuropharmacology*. 2000;39(5):835-841.

© 2023 The Authors. Published by Wolters Kluwer Health, Inc. on behalf of Academy of Neurologic Physical Therapy, APTA

39. van der Lee JH, Beckerman H, Lankhorst GJ, Bouter LM. The responsiveness of the Action Research Arm test and the Fugl-Meyer Assessment scale in chronic stroke patients. *J Rehabil Med*. 2001;33(3):110-113. doi:10.1080/165019701750165916.
40. Kwakkel G, Lannin NA, Borschmann K, et al. Standardized measurement of sensorimotor recovery in stroke trials: consensus-based core recommendations from the Stroke Recovery and Rehabilitation Roundtable. *Int J Stroke*. 2017;12(5):451-461. doi:10.1177/1747493017711813.
41. Sullivan KJ, Tilson JK, Cen SY, et al. Fugl-Meyer assessment of sensorimotor function after stroke: standardized training procedure for clinical practice and clinical trials. *Stroke*. 2011;42(2):427-432. doi:10.1161/strokeaha.110.592766.
42. Sullivan JE, Crowner BE, Kluding PM, et al. Outcome measures for individuals with stroke: process and recommendations from the American Physical Therapy Association neurology section task force. *Phys Ther*. 2013;93(10):1383-1396. doi:10.2522/ptj.20120492.
43. Woodbury ML, Velozo CA, Richards LG, Duncan PW, Studenski S, Lai SM. Dimensionality and construct validity of the Fugl-Meyer assessment of the upper extremity. *Arch Phys Med Rehabil*. 2007;88(6):715-723. doi:10.1016/j.apmr.2007.02.036.
44. Shi D, Chen X, Li Z. Diagnostic test accuracy of the Montreal Cognitive Assessment in the detection of post-stroke cognitive impairment under different stages and cutoffs: a systematic review and meta-analysis. *Neurol Sci*. 2018;39(4):705-716. doi:10.1007/s10072-018-3254-0.
45. Hernández ED, Galeano CP, Barbosa NE, et al. Intra- and inter-rater reliability of Fugl-Meyer Assessment of Upper Extremity in stroke. *J Rehabil Med*. 2019;51(9):652-659. doi:10.2340/16501977-2590.
46. Lambercy O, Lehner R, Chua K, et al. Neurorehabilitation From a distance: can intelligent technology support decentralized access to quality therapy? *Front Robot AI*. 2021;8:612415. doi:10.3389/frobt.2021.612415.
47. Kerr A, Grealy MA, Kuschmann A, Rutherford R, Rowe P. A Co-creation centre for accessible rehabilitation technology. Brief research report. *Front Rehabil Sci*. 2022;2:820929. doi:10.3389/fresc.2021.820929.
48. Karimi M, Lee EC, Couture SJ, et al. National Survey Trends in Telehealth Use in 2021: Disparities in Utilization and Audio vs. Video Services. https://aspe.hhs.gov/sites/default/files/documents/4e1853c0b4885112b2994680a58af9ed/telehealth-hps-ib.pdf.
49. Health Resources and Services Administration (HRSA). Telehealth: Health care from the safety of our homes. *U.S. Department of Health and Human Services (HHS)*. https://telehealth.hhs.gov/. Accessed August 2022, 2022.
50. United States Census Bureau. Computer and Internet Use in the United States: 2018. https://www.census.gov/newsroom/press-releases/2021/computer-internet-use.html. Published 2022.
51. Mokkink LB, Terwee CB, Patrick DL, et al. The COSMIN checklist for assessing the methodological quality of studies on measurement properties of health status measurement instruments: an international Delphi study. *Qual Life Res*. 2010;19(4):539-549. doi:10.1007/s11136-010-9606-8.
52. Terwee CB, Prinsen CAC, Chiarotto A, et al. COSMIN methodology for evaluating the content validity of patient-reported outcome measures: a Delphi study. *Qual Life Res*. 2018;27(5):1159-1170. doi:10.1007/s11136-018-1829-0.
53. Akyea RK, Vinogradova Y, Qureshi N, et al. Sex, age, and socioeconomic differences in nonfatal stroke incidence and subsequent major adverse outcomes. *Stroke*. 2021;52(2):396-405. doi:10.1161/strokeaha.120.031659.
54. GBD 2019 Stroke Collaborators. Global, regional, and national burden of stroke and its risk factors, 1990-2019: a systematic analysis for the Global Burden of Disease Study 2019. *Lancet Neurol*. 2021;20(10):795-820. doi:10.1016/s1474-4422(21)00252-0.
55. Almathami HKY, Win KT, Vlahu-Gjorgievska E. Barriers and facilitators that influence telemedicine-based, real-time, online consultation at patients' homes: systematic literature review. *J Med Internet Res*. 2020;22(2):e16407. doi:10.2196/16407.
56. Federal Communications Commission. Affordable Connectivity Program. https://www.fcc.gov/acp.

Erratum

Essential Competencies in Entry-Level Neurologic Physical Therapist Education: Erratum

In the article[1] mentioned above, Dorian K. Rose's affiliation was incomplete. The correct affiliation is listed below. This has also been corrected in the online version of the article.

Dorian K. Rose, PhD, MS, PT, Research Professor, University of Florida, Gainesville, Florida; Research Scientist, Brooks Rehabilitation, Jacksonville, Florida; Research Health Scientist, Malcom Randall VA Medical Center, Gainesville, Florida.

Reference

1. Held Bradford EC, Fell N, Zablot CM, Rose DK. Essential competencies in entry-level neurologic physical therapist Education. *J Neuro Phys Ther*. 2023;47(3):174-183.

DOI: 10.1097/NPT.0000000000000460

 © 2023 The Authors. Published by Wolters Kluwer Health, Inc. on behalf of Academy of Neurologic Physical Therapy, APTA