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ORIGINAL RESEARCH

Acceleration Metrics Are Responsive to Change in Upper Extremity Function of Stroke Survivors

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Abstract

Objectives: To (1) determine whether acceleration metrics derived from monitoring outside of treatment are responsive to change in upper extremity (UE) function; and secondarily to (2) compare metric values during task-specific training and while in the free-living environment, and (3) establish metric associations with an in-clinic measure of movement capabilities.

Design: Before-after observational study.

Setting: Inpatient hospital (primary purpose); outpatient hospital (secondary purpose).

Participants: Individuals (n=8) with UE hemiparesis <30 days poststroke (primary purpose); individuals (n=27) with UE hemiparesis ≥6 months poststroke (secondary purpose).

Intervention: The inpatient sample was evaluated for UE movement capabilities and monitored with wrist-worn accelerometers for 22 hours outside of treatment before and after multiple sessions of task-specific training. The outpatient sample was evaluated for UE movement capabilities and monitored during a single session of task-specific training and the subsequent 22 hours outside clinical settings.

Main Outcome Measures: Action Research Arm Test (ARAT) and acceleration metrics quantified from accelerometer recordings.

Results: Five metrics improved in the inpatient sample, along with UE function as measured on the ARAT: use ratio, magnitude ratio, variation ratio, median paretic UE acceleration magnitude, and paretic UE acceleration variability. Metric values were greater during task-specific training than in the free-living environment, and each metric was strongly associated with ARAT score.

Conclusions: Multiple metrics that characterize different aspects of UE movement are responsive to change in function. Metric values are different during training than in the free-living environment, providing further evidence that what the paretic UE does in the clinic may not generalize to what it does in everyday life.

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Upper extremity (UE) hemiparesis after stroke is one of the leading causes of disability, with only a small percentage of survivors recovering sufficiently to engage in their professional and private lives as they did before stroke onset.[1-3] Presently, however, there is a limited ability to objectively evaluate UE function in the free-living environment (ie, outside clinical settings). This is problematic because a major purpose of rehabilitation and the associated health care costs is to enhance everyday function and independent living. Furthermore, it is routinely assumed that improvements observed in the clinic generalize to the free-living environment, but there is evidence to suggest that this assumption may not always hold true.[4]

Body-worn sensors, such as accelerometers, noninvasively measure movement production outside clinical settings. The lack of a discernible difference in signals resulting from task-specific (eg, reaching or grasping) and non−task-specific UE movement (eg, arm swing during gait) limits what can be understood regarding qualitative aspects of UE motor behavior. To overcome this limitation, some recent approaches have incorporated machine learning,[5] spectral analysis,[6] and other techniques[7] to probe task-specific UE behaviors. Progress has been limited, however, because of the considerable intra- and interindividual variability in human movement.[8,9] Diminishing time available for the delivery of rehabilitation services[10] also limits the practicality of working with sophisticated data sets in clinical practice.

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Another previously used methodology involves transforming the signals recorded in the free-living environment into metrics that correlate with clinical scales of UE function. For example, the absolute duration of paretic UE movement[11] and the ratio of movement between paretic and nonparetic UEs[12,13] correlate with commonly used clinical assessments of UE function. The advantage of this approach is that the metrics are readily quantifiable and derived from wireless devices that are minimally invasive. Existing metrics pertain solely to the duration of paretic UE movement during the monitoring period. It is possible that other movement characteristics can be captured using these devices, providing greater insight into UE motor behavior in the free-living environment. A deeper understanding of what patients do in their everyday lives may afford clinicians a means to objectively evaluate function and set benchmarks for treatment, as well as develop and adapt rehabilitation protocols on an individual basis.

To this end, recent work[14] has established the convergent validity of metrics that capture different aspects of how UE movement occurs during task-specific behaviors. Whether these metrics are responsive to change in UE function outside treatment settings is not known. It is also not understood how metric values during motor retraining compare with values captured while in the free-living environment. Thus, the primary purpose of the current study was to further examine the validity of these metrics by assessing their responsiveness to change in UE function. The secondary purposes were 2-fold: The first was to compare metric values during task-specific training and while in the free-living environment. The second was to establish metric associations with a widely used clinical scale of UE function. Based on previous findings,[14] we hypothesized that ratio and paretic UE metrics, particularly those related to acceleration variability, would be responsive to changes in UE function after treatment and exhibit a strong association with the Action Research Arm Test (ARAT) score. We also hypothesized that metric values would be higher during task-specific training than in the free-living environment.

Methods

Participants

To determine responsiveness to change in UE function, metric values were derived from monitoring outside of treatment at a pretest and posttest that took place before and after multiple sessions of high-repetition, task-specific training in an inpatient sample (≤30d poststroke, n=8). The outpatient sample (≥6mo poststroke, n=27) was recruited as part of an ongoing clinical trial (NCT 01146379). Participants in this sample were monitored during a single training session and in the free-living environment to compare metric values in both contexts and establish metric associations with the ARAT score. Inclusion and exclusion criteria for each sample are shown in table 1. All participants provided informed consent according to procedures approved by the institutional review boards at Northwestern University (inpatient sample) and Washington University (outpatient sample).

List of abbreviations:

ARAT **Action Research Arm Test**
UE **upper extremity**

Table 1 Inclusion and exclusion criteria for inpatient and outpatient samples

Inclusion Criteria	Inpatient	Outpatient
Motricity Index score of 42–93	X	
ARAT score of 10–49		X
Diagnosis of ischemic or hemorrhagic stroke with residual UE paresis, as determined by a stroke neurologist	X	X
Sufficient cognitive function to follow commands, as indicated by a score of 0–1 on the NIHSS	X	X
Age ≥18y	X	X
Exclusion Criteria		
Severe hemispatial neglect, as indicated by a score of 2 on the NIHSS Extinction and Inattention subtest	X	
Psychiatric diagnosis		X
Other neurologic diagnoses		X
History of neurosurgical intervention		X
Currently pregnant	X	X
History of stroke >1wk before the current index stroke affecting the same side of the body	X	

Abbreviation: NIHSS, National Institutes of Health Stroke Scale.

Procedure

Participants in both samples engaged in individualized, task-specific training according to a previously established protocol.[15,16] Tasks used for training were identified by participants as being meaningful to them and requiring improvement to enhance their independence and performance in daily living. Inpatient and outpatient participants completed an average of 13 and 28 sessions, respectively. All participants were monitored via wireless devices containing a triaxial, solid-state digital accelerometer[a] (dimensions, 4.6×3.3×1.5cm; weight, 19g [range, ±8g]) strapped to the dorsal side of both wrists just proximal to the radial and ulnar styloid. Inpatient participants were monitored for 22 hours after the pretest and posttest. The outpatient sample was monitored during the 24th training session and subsequent 22 hours. The 24th treatment session was chosen because participants were familiar with procedures and accustomed to wearing the devices at this point in the overall trial. All participants reported that the monitoring period was representative of a typical day. Paretic UE function was evaluated before and after the intervention for the inpatient sample and just before the 24th training session for the outpatient sample. UE function was evaluated with the ARAT, a test consisting of 19 items divided into 4 subscales: grasp, grip, pinch, and gross movement. The ARAT was chosen because this clinical assessment is a valid and reliable test of UE function,[17-19] sensitive to change in function after stroke,[18-22] and widely used in clinical trials.[23,24] The intra- and interrater reliability of the ARAT is established.[17] Moreover, the ARAT is strongly correlated with other accepted measures of UE function.[25,26] Blinded raters evaluated UE function for the outpatient sample; a separate rater who was not blinded performed evaluations for the inpatient sample.