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ORIGINAL ARTICLE

Network of Movement and Proximity Sensors for Monitoring Upper-Extremity Motor Activity After Stroke: Proof of Principle

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Abstract

Objective: To test the convergent validity of an objective method, Sensor-Enabled Radio-frequency Identification System for Monitoring Arm Activity (SERSMAA), that distinguishes between functional and nonfunctional activity.

Design: Cross-sectional study.

Setting: Laboratory.

Participants: Participants (N=25) were ≥0.2 years poststroke (median, 9) with a wide range of severity of upper-extremity hemiparesis.

Interventions: Not applicable.

Main Outcome Measures: After stroke, laboratory tests of the motor capacity of the more-affected arm poorly predict spontaneous use of that arm in daily life. However, available subjective methods for measuring everyday arm use are vulnerable to self-report biases, whereas available objective methods only provide information on the amount of activity without regard to its relation with function. The SERSMAA consists of a proximity-sensor receiver on the more-affected arm and multiple units placed on objects. Functional activity is signaled when the more-affected arm is close to an object that is moved. Participants were videotaped during a laboratory simulation of an everyday activity, that is, setting a table with cups, bowls, and plates instrumented with transmitters. Observers independently coded the videos in 2-second blocks with a validated system for classifying more-affected arm activity.

Results: There was a strong correlation ($r=.87$, $P<.001$) between time that the more-affected arm was used for handling objects according to the SERSMAA and functional activity according to the observers.

Conclusions: The convergent validity of SERSMAA for measuring more-affected arm functional activity after stroke was supported in a simulation of everyday activity.

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Data and models of disability suggest that what patients can do with a neurologically impaired limb (ie, their motor capacity), and what they actually do with that limb in their regular environment (ie, their motor performance), need to be measured separately.[1] Research on monkeys after surgical abolition of sensation from a forelimb demonstrates that such animals do not use their deafferented limb spontaneously, even after regaining sufficient motor capacity to do so several weeks after surgery because of a process named learned nonuse.[2] As predicted by the deafferented monkey research, studies of adults ≥3 months poststroke

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show that capacity to complete tasks with the more-affected arm on motor tests in the treatment setting often departs from the amount of spontaneous use of that arm in daily life.[3-7] The *International Classification of Functioning, Disability and Health* also supports the separate study of motor capacity and performance.[8]

In response to this need, both subjective and objective methods for measuring more-affected arm use in daily life have been developed.[1,9] Subjective measures, such as the Motor Activity Log (MAL),[3,10] are vulnerable to common self-report biases despite strong clinimetric data. The objective methods, of which the most widely used is accelerometry,[11-15] are free from these types of bias but cannot discriminate whether movement by the more-affected arm is functional or nonfunctional and cannot identify what tasks have been performed. Recently developed systems of physical sensors, such as Inertial Measurement Units, have the potential to discriminate between functional and nonfunctional movements. However, at present, they have only been shown to index quality of arm movement after stroke on standardized motor tests in the laboratory.[16,17]

This proof-of-principle study in adults with upper-extremity hemiparesis because of stroke examines the convergent validity of a distributed network of physical sensors for measuring the amount of more-affected arm movement related to functional activity and for identifying what tasks have been performed with the more-affected arm. The sensor network is named the Sensor-Enabled Radio-frequency Identification System for Monitoring Arm Activity (SERSMAA). It departs from existing approaches by placing sensors on objects in addition to the patient. Twenty-five stroke survivors had their activity monitored with a SERSMAA prototype and were videotaped during a laboratory simulation of an everyday activity, that is, setting a table with cups, bowls, and plates. The correspondence was then examined between the amount of time objects were handled with the more-affected arm, as determined by the SERSMAA, and the duration of task-related activity with the more-affected arm, as determined by an independent pair of observers using a validated behavioral coding system. Additionally, the identity of the objects handled with the more-affected arm according to the SERSMAA and the behavioral coding was compared.

Methods

Participants

Participants (N=25) were adults (median age, 62.6y; range, 43−94y; 8 women) after cortical or subcortical stroke (median chronicity, 9.0y; range, 0.2−60.9y) of any etiology with a wide range of severity of upper-extremity hemiparesis. Principal exclusion criteria were (1) inability to complete the 3-step command from the Folstein Mini-Mental State Examination, that is, inability to understand and follow verbal directions; (2) unstable medical condition; and (3) condition other than stroke that might affect arm function. Spinal cord strokes were also excluded from the study. Table 1 summarizes participant characteristics. The institutional review board of the university approved the study procedures, and all participants gave informed consent.

List of abbreviations:

FAABOS	**Functional Arm Activity Behavioral Observation System**
MAL	**Motor Activity Log**
RF	**radio-frequency**
RFID	**radio-frequency identification**
SERSMAA	**Sensor-Enabled Radio-frequency Identification System for Monitoring Arm Activity**

Apparatus

The design and operation of the SERSMAA prototype tested is diagrammed in figure 1, subsequently described, and discussed in detail in Barman et al.[19] Barman[19] reports testing this prototype in young adults without upper-extremity impairment under highly controlled conditions in a laboratory setting. The SERSMAA reliably and validly measured the amount of time household objects were handled with the arm of interest in this able-bodied population. Sensitivity and specificity for detecting the identity of the objects handled were >99%.

Radio-frequency transmitters[a] (7.8×3.8×2cm; 50g) were paired with movement sensors and were attached to the objects to be handled using a hook and loop fastener. Each RF transmitter sent 30-Hz oscillator signals at a fixed low frequency of approximately 10.7kHz with a unique signature. The choice of a low frequency permitted sensing proximity of the receiver and transmitter over short distances of 1 to 23cm, that is, for detecting when the more-affected arm was adjacent to an instrumented object.[19] The movement sensors were GT1M activity monitors[b]

Table 1 Demographic and stroke-related characteristics of the participants (N=25)

Characteristic	Value
Demographic	
Age (y)	62.0±13.4
Female	8 (32)
Ethnicity	
White	12 (48)
Black	12 (48)
Asian	1 (4)
Right dominant preinjury	21 (84)
Stroke-related	
Time poststroke (y)	9.0±12.2
Paresis of dominant side	9 (36)
Severity of more-affected arm motor impairment*	
Grade 2 (mild/moderate)	16 (64)
Grade 3 (moderate)	3 (12)
Grade 4 (moderately severe)	2 (8)
Grade 5 (severe)	4 (16)
Primary mode of ambulation during daily life†	
Independent	9 (36)
Walker/cane	15 (60)
Wheelchair	1 (4)

NOTE. Values are mean ± SD or n (%).

* Participants were assigned a grade by a therapist based on active range of motion available at the upper-extremity joints. This classification system is described in Taub et al.[18]

† Primary mode of ambulation is defined as the one used more than two thirds of the time.