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ORIGINAL RESEARCH

Concurrent and Predictive Validity of Arm Kinematics With and Without a Trunk Restraint During a Reaching Task in Individuals With Stroke

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Abstract

Objective: To examine the concurrent and predictive validity of measurements of kinematic variables during reaching tasks with and without a trunk constraint in individuals with stroke.

Design: Randomized controlled trials.

Settings: Hospitals and a laboratory.

Participants: Individuals with stroke (N=95) enrolled in previous and ongoing clinical trials.

Interventions: Upper limb training protocols were 90 to 120 minutes of intervention every weekday for 3 to 4 weeks.

Main Outcome Measures: Functional capacity was assessed using the Action Research Arm Test and motor impairment using the Fugl-Meyer Assessment for the Upper Extremity. Movement kinematics were measured during a reaching task with and without a trunk constraint. We derived 5 endpoint control variables and 3 joint recruitment variables for estimating concurrent and predictive validity.

Results: The adjusted R^2 values for the constraint tasks ranged from .24 to .38 and for the unconstraint tasks from .29 to .40. Movement time was the most prominent kinematic variable for the Fugl-Meyer Assessment for the Upper Extremity before and after the intervention ($P<.05$). For the Action Research Arm Test, movement time and endpoint displacement were the most significant variables before and after the intervention, respectively ($P<.05$).

Conclusions: Measuring kinematic performance during an unconstrained task is appropriate and possibly sufficient to represent motor impairment and functional capacity of individuals with stroke. Movement time is the dominant variable associated with motor impairment and functional capacity, and endpoint displacement is unique in reflecting functional capacity of individuals with stroke.

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Brain damage caused by stroke often results in persistent upper limb impairment that strongly disrupts the ability of the recovering individual to perform functional activities.[1-3] Objective and subjective clinical scales are usually used in the clinic to evaluate the impairment and recovery of upper limb function.[4-7] Although clinical scales, such as the Wolf Motor Function Test and the Action Research Arm Test (ARAT), are considered sensitive and specific measures to reveal stroke-related experience,[8,9] they lack quantitative measurements to characterize the specific manner in which the movement components and control have changed.[10-13] Kinematic analysis may allow for a more detailed assessment of motor control parameters and could provide detailed and functionally relevant assessments of everyday tasks such as the ability to perform movements of the extremities in response to environmental demands. At the biomechanical level, kinematics mainly concern the status of joint angles (eg, the angle of shoulder flexion) and endpoint variables (eg, movement time),[14] which

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can provide spatial and temporal information on motor control/performance.[13,15-17] According to the International Classification of Functioning,[18] kinematic data obtained from a functional task (ie, reaching for an object) might reflect not only the level of body function/impairment but also the level of activity whether the individual is capable of performing.

Reaching kinematics are widely used to compare voluntary movement in healthy participants with movements in individuals with stroke.[17,19-23] Healthy people generated trunk forward flexion to incorporate an extra degree of freedom for reaching the target beyond 90% of the arm length[13]; however, stroke survivors exerted excessive trunk motion during reaching within and beyond the 90% of the arm length threshold.[24] This indicates that arm-trunk coordination and joint recruitment of the upper limb are compromised after stroke and that patients use compensatory strategies for accomplishing reaching tasks.[24]

Performance of a reaching task without the benefit of a trunk restraint (ie, in a natural context) could allow for the involvement of trunk-arm motion but does not capture the real potential of the upper limb functional capacity.[17,25] Reaching with the trunk constrained was observed to occur with greater voluntary movement in the shoulder and elbow joints than that under the unconstrained condition and has resulted in improved movement in individuals with hemiparesis.[25] Reaching with the trunk constrained can also fully reflect motor performance or reveal motor impairment in the upper limbs without the influence of trunk motion.

Research on unconstrained reaching tasks was conducted to demonstrate different kinematic performance among different task demands or treatment approaches.[21,26,27] Other research[13,26,28-30] has used a restrained trunk condition during a reaching task to examine the treatment effect or to evaluate reaching performance in stroke survivors. However, these kinematic studies used only 1 task performed either with[21,26,28,30,31] or without[17,19,24,32,33] a trunk constraint.

To improve the clinical utility of kinematic reaching assessments, evidence on more comprehensive psychometric properties during trunk constrained and unconstrained tasks is of particular interest to clinical practice and for the evaluation of treatment effects. For clinical data, concurrent validity provides evidence to demonstrate which kinematic variables correlate well with widely used clinical scales during motor recovery (Fugl-Meyer Assessment [FMA] and ARAT). Predictive validity demonstrates which kinematic variables better predict motor recovery after an intervention. Only a limited number of studies have reported the concurrent validity of kinematic analyses of reaching and have revealed kinematic variables such as movement time, trunk displacement, and movement smoothness[10,21,32,34] reflecting motor impairment[10,21,35-38] and functional capacity.[39]

The objective of this study was to investigate the concurrent validity of kinematic variables before and after the intervention and the predictive validity after the intervention during reaching tasks with and without a trunk constraint in individuals with stroke. The FMA and the ARAT were chosen as the criterion standards for the evaluation of concurrent and predictive validity of the selected kinematic variables because each clinical measurement, respectively, represents motor impairment and functional capacity for performing daily activities classified by the International Classification of Functioning framework.[38,39] We hypothesized that kinematic variables would account for motor impairment and functional capacity represented by the FMA and ARAT during reaching tasks performed with and without a trunk constraint. In addition, we expected a moderate correlation between FMA/ARAT and kinematic measures on the basis of previous research findings.[10,17,21,35] Because the FMA and ARAT each have a unique assessment focus (motor impairment and functional capacity, respectively), the combination of kinematic variables capable of explaining the measured psychometric properties will be different for each test. Therefore, this study will measure the concurrent and predictive validity of the optimized combination of kinematic variables to predict FMA and ARAT scores under different testing conditions.

List of abbreviations:

ARAT	**Action Research Arm Test**
FMA	**Fugl-Meyer Assessment**
FMA-UE	**Fugl-Meyer Assessment for the Upper Extremity**

Methods

Participants

Data were obtained from 95 individuals with stroke who were enrolled in previous[30,40-42] and ongoing clinical trials investigating the effects of upper limb training protocols and were assessed for motor impairment and functional capacity before and after the training protocols. The beginning and end dates of the enrollment were January 2, 2006 and December 31, 2012. The ethics committees of the participating sites approved this study. All participants provided informed consent in accordance with the Declaration of Helsinki before entering the study. Detailed demographic characteristics are listed in table 1.

Inclusion and exclusion criteria

The inclusion criteria were as follows: (1) diagnosis of first-ever stroke or multiple strokes on the same side of the brain; (2) stroke that occurred >1 month before participation; (3) ability to follow verbal instructions (Mini-Mental State Examination score, $\geq$24)[43]; (4) the upper limb motor severity score of $\geq$III as rated on the Brunnstrom stage; and (5) the Modified Ashworth Scale score of $\leq$2 in any joint.[44] The exclusion criteria were as follows: (1) other neurological conditions; (2) orthopedic impairments in the upper limbs; and (3) any health problem that could limit participation in the study.

Kinematic measurement

We used a 7-camera Vicon MX motion analysis system,[a] with the sampling rate of 120Hz, to capture kinematics of the reaching motion. A desk bell (diameter, 9.7cm; height, 4.8cm) was used as a target for participants to reach and press. Twelve markers were placed on the more affected arm on the bony prominence at the following landmarks: C7, T4, jugular notch of the sternum, head of the clavicle, acromion process, lateral epicondyle of the humerus, midpoint of the humerus, the radial and ulnar styloid process of the wrist, and index fingernail (fig 1).

Kinematic performance was assessed before and after the intervention using the same testing protocol. Each movement began with the index finger resting at the starting location and ended with the participant pressing the bell with their index finger. Kinematic data were filtered with a low-pass, second-order Butterworth filter with a cutoff frequency of 5Hz. We used a customized LabVIEW program[b] to obtain the following endpoint control variables derived