A computational approach to quantify movement impairment after stroke

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Background.

Knowing movement quality during stroke rehabilitation is important, as it helps clinicians tailor treatment strategy in real time. However, current approaches for quantifying upper extremity (UE) movement abnormality are inadequate. The Fugl-Meyer Assessment (FMA), the gold-standard instrument used to measure impairment, is limited by rater subjectivity and a coarse grading scale. These limitations preclude an objective and nuanced characterization of abnormality and recovery. To overcome these limitations, we combined advanced motion capture and computational methods to quantify abnormalities in paretic UE movement.

Methods.

Data were collected from 9 stroke patients (6F/3M; mean age 57 years; 5L/4R paresis; mean FMA score 38) and 8 healthy controls (4F/4M; mean age 73 years; mean FMA score 58). A trained assessor administered and scored the FMA, consisting of 14 items. Subjects wore 9 inertial measurement units (IMUs) on the axial (pelvis and lower and upper thoracic spine), proximal (arms), and distal (hands and forearms) segments of the upper body. The sensor system generated 3D linear accelerations, 3D orientations, quaternions, and joint angles at 100 Hz. Simultaneously recorded video was used to segment each item of the FMA, which also segmented the corresponding IMU data. To capture the differences between impaired and unimpaired movement, we applied dynamic time warping (DTW) to the IMU data from stroke patients and healthy controls. To account for inter-subject variability of each subject group, we clustered the DTW distances using Gaussian mixture models (GMM). To generate a continuous metric of movement impairment, we computed Mahalanobis distances (MD) from healthy GMM clusters to estimate impairment level. To ascertain the validity of this approach for quantifying impairment, we computed Pearson's correlation between the MD and the gold-standard FMA scores.

Results.

Comparing MDs generated with all of the sensors against the FMA scores, we observed a correlation of $r = -0.72$, $p < 0.05$. In other words, larger MDs (i.e., higher distance from healthy controls) were associated with lower FMA scores (i.e., more impairment). Comparing MDs generated from the axial, proximal, and distal sensors against the FMA scores, we found moderate-to-high levels of correlation: axial $r = -0.46$, $p < 0.05$; proximal $r = -0.76$, $p < 0.05$; distal $r = -0.70$, $p < 0.05$. Combining data streams from the proximal and distal segments resulted in a moderately higher correlation $r = -0.79$, $p < 0.05$. We also found that MDs could discern gradations of impairment that the FMA could not.

Conclusion.

Here, we present a proof-of-principle approach for quantifying movement impairment using wearable sensors and computational methods. Our approach combined high dimensional motion data with dynamic time warping, Gaussian mixtures, and Mahalanobis distances to provide a fine-grained capture of impairment. Using FMA scores as the gold-standard comparison, we ascertained the concurrent validity of this approach. Given its continuous metrics, our approach can provide a more nuanced measurement of impairment not captured by the FMA. Future work will utilize the data from the axial IMUs to quantify compensatory movements (alternative movement strategies to circumvent impairment), for which no standard measurements currently exist. In summary, we propose an approach that may expand our capabilities for detecting and mitigating impairment after stroke.