Upper extremity kinematics of a 3D reach-to-grasp-to-mouth task in sub-acute stroke survivors in comparison with healthy controls [version 1; peer review: awaiting peer review]

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Abstract

Background

Only 5–20% of stroke survivors exhibit almost complete motor recovery at six months post-stroke. The Stroke Recovery and Rehabilitation Roundtable (SRRR) Taskforce has recommended the use of performance assays that predict recovery. However, not much is known about the differences across various stroke severity groups. The purpose of this study was to determine whether kinematic parameters of time, average velocity, shoulder angles and elbow angles were able to distinguish upper extremity movement capacity in individuals with varying levels of stroke severity and healthy controls.

Methods: This is a cross-sectional study, which is part of a large cohort study. 27 sub-acute stroke survivors (58.8 ± 12.7 years; 18 males, 9 females; categorized into mild (51-66), moderate (25-50) and severe (<25) Fugl Meyer Assessment of Upper Extremity (FM-UE) categories and 10 healthy controls (48.9 ± 13.7 years; 6 males, 4 females) performed 20 trials of a 3D reach-to-grasp-to-mouth task. Kinematic parameters were analyzed using a one-way ANOVA test.

Results: Movement time was significantly different between severe and all other stroke groups (mild [p<0.001], moderate [p<0.001]) and healthy controls (p<0.001). Average velocity was significantly different between all three stroke groups (mild [p=0.03], moderate [p<0.001], severe [d= -3.7, p<0.001]) and healthy controls. Elbow flexion was significantly different between moderate and severe stroke groups (p=0.009). Elbow extension showed significant differences between
mild and moderate stroke groups (p<0.001). Shoulder extension exhibited significant differences between mild (p<0.001), moderate (p<0.001) and severe (p<0.001) and healthy controls.

**Conclusions:** Kinematic analysis of a reach-to-grasp-to-mouth task helps to differentiate between varying groups of severity post-stroke such as mild, moderate and severe, based on Fugl Meyer for Upper Extremity scores.

**Keywords**
Hemiparesis; Kinematics; Upper limb recovery;

This article is included in the Manipal Academy of Higher Education gateway.
Introduction

Stroke is the second commonest cause of mortality. In 2019, globally, there were 12.2 million incident strokes and 6.55 million deaths due to stroke. Along with being a global phenomenon, stroke is also one of the crucial triggers of early mortality and disability in low as well as low-to-middle income countries. These countries experience demographic changes and an increased prevalence of modifiable risk factors.

Only around 5-20% of stroke survivors exhibit almost complete upper extremity (UE) recovery at six months after a stroke and just half of them are able to return to work. This primarily could be attributed to persisting UE impairments in approximately two-thirds of stroke survivors. Decreased UE capacity in the form of dysfunction of the arm and hand are predominant contributors toward deficits in performing common activities such as reaching for a target and lifting and holding on to objects thus having a negative effect on participation. These maneuvers are important to perform few of the commonest activities of daily living (ADLs). Consequently, the above mentioned UE impairments could be one of the main factors that could affect an individual’s quality of life (QOL). Hence, the majority of neurorehabilitation research studies focus on the effectiveness of interventions targeting UE motor recovery.

Having said this, post-stroke recovery transpires through a multifaceted combination of recovery mechanisms paired with certain learning-based processes that include spontaneous biological recovery, compensation and behavioral restitution (also known as true recovery). Spontaneous biological recovery refers to betterment in post-stroke UE recovery even in the absence of a precise and goal-oriented treatment. Compensatory strategies include new behavioral approaches by using intact muscles, joints, and effectors in the affected limb, to accomplish the desired task or goal. Behavioral restitution or true recovery on the other hand, has been defined as a return to near normal patterns of motor control with the impaired extremity. It is the return of some or all of the normal behaviors that were available pre-stroke. Some amount of neural repair is necessary for recovery to occur in its true form. Although it is incomplete, some degree of true recovery is almost always achieved post-stroke. It could be the result of the contribution from descending inputs arising from bilateral hemispheres, which could also be responsible in shaping the final motor command reaching alpha motor neurons that innervate the UE musculature for optimal movement control.

In conjunction with this, certain other factors have also been found to influence post-stroke recovery which include age, stroke severity, lesion volume or lesion location, uncontrolled hypertension, hyper glycaemia, inflammation, intensity of therapy, initial motor impairment, degree of injury to Corticospinal Tract (CST), mood, neglect and incontinence. Numerous techniques exist for subjective as well as objective measurement of the aforementioned factors. Traditionally, UE deficits post-stroke are evaluated using established clinical scales such as Fugl Meyer Assessment of UE and Action Research Arm Test (ARAT). However, a drawback of these assessments is that they are insufficiently sensitive for capturing the quality of sensorimotor performance because of the use of ordinal scales.

This shortcoming could be fulfilled by comprehensive neuroimaging techniques such as Computerized Tomography (CT), Magnetic Resonance Imaging (MRI) with diffusion weighted images, Magnetic Resonance angiography and/or neurophysiological measures namely Electroencephalogram (EEG), Motor Evoked Potentials (MEPs) or Somatosensory Evoked Potentials (SSEPs), and lastly biomechanical measures which include kinematic analysis and Electromyography (EMG). These techniques have been shown to discern the pathophysiological basis of an injury and may be better able to gauge a patient’s recovery potential. Of these measures, kinematic parameters can be used to assess an individual’s movement quality. They help in providing objective metrics that have the potential to sensitively capture movement quality and enable the monitoring of motor recovery. Several studies incorporating measures such as 3-D kinematics have shown aberrant motor control post-stroke. Most of these studies explored kinematic variables of movement time, mean velocity, number of velocity peaks and movement smoothness. However, these studies included mild and moderate stroke participants who were given a non-functional task such as the nine-hole peg test or a point-to-target task.

The previous studies that have incorporated kinematic analysis as an assessment method, display a lack of standardization of assessment tasks, measurement systems and kinematic metrics. Consequently, with the aim of bridging this methodological gap, the Stroke Recovery and Rehabilitation Roundtable (SRRR) Taskforce has recommended the use of performance assays such as grip and pinch strength, 2D and 3D kinematic analysis and finger individuation, that predict post-stroke recovery. Nevertheless, most kinematic studies that have investigated UE reaching have demonstrated significant differences between healthy controls and stroke survivors in terms of motor task performance as evidenced by kinematic variables. However, there is a gap in literature addressing kinematic analysis of severely affected stroke participants mainly because of task-related feasibility issues. Thus, studies that investigate functional tasks with ecological validity in stroke survivors are warranted. Hence, the purpose of this study was to assess differences in kinematic parameters such as movement time, average velocity and shoulder and elbow angles between stroke survivors (with different levels of stroke severity – mild, moderate and severe) and healthy controls for a reach-to-grasp-to-mouth task.
Hypothesis
We hypothesized that the kinematic parameters of movement time, average velocity and shoulder and elbow range of motion (ROM) may exhibit differences when compared across the three severity levels post-stroke and also with healthy controls.

Methods
This study has been reported using the Strengthening the Reporting of Observational studies in Epidemiology (STROBE) checklist (Table 1).21

Study design, ethical approval and trial registration
This is a cross-sectional study, which is part of a large prospective longitudinal cohort study that has been carried out from January 2019 to March 2022. The study protocol was approved by the Institutional Research Committee (IRC), University Research Committee and Institutional Ethics Committee (IEC), (IEC/812/2018). The study has been registered under the Clinical Trials Registry (CTRI number: CTRI/2019/04/018774).

Setting
The study was carried out at the Stroke unit, Department of Neurology, and the Neuromotor Control Laboratory, Department of Physiotherapy in a large tertiary care hospital.

Participants
The participants in this study were patients with stroke admitted to the hospital stroke unit as well as healthy controls with no comorbidities who were recruited as a healthy control group.

Eligibility criteria
We included adults with first ever clinically defined stroke of either gender aged between 18 and 85 years. We also recruited a healthy control group of participants who were age- and gender-matched. We excluded individuals who were

| Table 1. STROBE Statement—Checklist of items that should be included in reports of cohort studies.33 |
|-----------------------------------------------|------|------------------|
| **Introduction**                              | Item No | Recommendation |
| Background/rationale                          | 1     | 5-8             |
| Hypothesis                                   | 2     | 8               |
| **Methods**                                   |       |                 |
| Study design                                  | 3     | 8               |
| Setting                                       | 4     | 8               |
| Participants                                  | 5     | 9               |
| Variables                                     | 6     | 9-13            |
| Data sources/measurement                      | 7     | 9-13            |
| Study size                                    | 8     | 13              |
| Quantitative variables                        | 9     | -               |
| Statistical methods                           | 10    | 13, 14          |
| **Results**                                   |       |                 |
| Participants                                  | 11    | 14              |
| Descriptive data                              | 12    | 14              |
| Main results                                  | 13    | 14-16           |
| **Discussion**                                |       |                 |
| Key results                                   | 14    | 16-20           |
| Limitations                                   | 15    | 19, 20          |
| Interpretation                                | 16    | 16-20           |
admitted after 7 days’ post-stroke, those who were unable to comprehend and follow simple commands (Montreal Cognitive Assessment Score <26),22 those who had undergone craniectomy or craniotomy, those with any pre-existing disorders which could affect the UE functions, individuals with other systemic disorders which could affect survival (e.g. malignant diseases, chronic liver or kidney disease, retroviral diseases), uncooperative patients, individuals with bilateral clinical stroke and those with any conditions precluding kinematic analysis.

Procedure

We screened all patients with stroke admitted to the Neurology unit for the eligibility criteria. A total of 27 people with stroke and 10 age- and gender-matched healthy controls were recruited based on the aforementioned eligibility criteria. A written informed consent was obtained from all participants before commencing the study procedure.

Variables

The primary investigator assessed variables comprising of demographic characteristics and kinematic parameters for both stroke patients as well as healthy controls. The demographic characteristics for stroke patients included age, sex, affected limb, stroke type, presence of active hand movement, post-stroke duration (days), Shoulder Abduction Finger Extension (SAFE) score and Fugl Meyer Assessment of Upper Extremity (FM-UE) score and were in accordance to the recommendations provided by the SRRR.23 Age and sex were also recorded for healthy controls.

Demographic characteristics:

1. Participants were classified into three categories according to their age: 18-55 years, 56-74 years, and >75 years;
2. Sex was reported as per the categories such as males, females or others;
3. Affected limb was reported as either right side or left side;
4. Stroke subtype was classified based on the Bamford classification24;
5. Presence of active hand movement was observed as the patient’s ability to actively move the hand independently at stroke onset;
6. SAFE score was reported as a score ranging from zero to 10, where a high score implies a better function;
7. The FM-UE scale was assessed as a stroke-specific motor impairment index measured on a three-point ordinal scale. It has a maximum score of 66, where a high score implies a better function.

Following the assessment of demographic characteristics, included patients with stroke and healthy controls underwent kinematic assessment. A 3D electromagnetic kinematic analysis tracking system (G4TM Polhemus, Vermont, USA) was used to carry out kinematic analysis for stroke survivors and healthy controls. The kinematic assessment setup included a systems electronic unit (electromagnetic source), two hubs with ports for connecting the sensors, five sensors, namely the sternal, acromion, upper arm, forearm and metacarpophalangeal, a USB (Universal Source Bus), a Bluetooth probe for transferring data from the sensors to the display unit, and a target in the form of a 6 cm diameter cone (Refer to Figure 1 for the equipment used in kinematic analysis and Figure 2 for the kinematic analysis setup).

This setup was used to kinematically analyse 20 trials of a reach-to-grasp-to-mouth task. While setting up the assessment unit, we first placed four sensors, the sternal, acromion, upper arm and forearm in their respective places. After this, the near and far target distances were marked on the table in front. The far target was set at the point where the participant’s distal wrist crease reached after completely extending the arm, and the near target was considered to be at 2/3rd of the far target distance. The computer and the systems electronic unit were then switched on. We used the PiMgR software (Patriot wellness) for performing kinematic analysis. Once switched on, the fifth sensor namely the metacarpophalangeal sensor was calibrated for both near and far targets. This was followed by measurement of the following distances:

a) Sternal to acromion sensor,

b) Acromion sensor to the olecranon process,
c) Upper arm sensor to the olecranon process,

d) Forearm sensor to the ulnar styloid process, and

e) The ulnar styloid process to metacarpophalangeal sensor.

Standardization of distances was done by performing distance calculation and calibration for each individual, so that variability in height and arm length could be accounted for. After measuring these distances, the participants were instructed to carry out the reach-to-grasp-to-mouth task which has been divided into the following 4 phases (refer to Figure 3 for procedure of carrying out the kinematic analysis task):

1. Reach-to-target, where the participant reaches in front to grasp a conical object of 6 cm diameter placed at the target distance (near/far);
2. Reach-to-drink, in which the participant raises the object towards the mouth;

3. Place the object back, where the participant returns the object to its original position and

4. Take UE to the starting position.

Each participant performed 20 trials of the same task, where they were randomly instructed to either reach the near (10 times) or the far target (10 times). After performing kinematic analysis for all stroke participants and healthy controls, the MATLAB © 2020 software was used to calculate the required kinematic parameters, see Table 2:\textsuperscript{14,23}:

1. Total movement time was defined as the time between the start and end of the reach-to-grasp-to-mouth task.
2. Peak velocity was measured as the overall maximal value of the velocity profile between movement onset and end whereas the average velocity was calculated for the MCP sensor for each phase separately first and then averaged out. The participants were asked to perform the task at a self-paced speed.

3. Shoulder flexion/extension range of motion (angles) between start and end of the task.

4. Elbow flexion/extension range of motion (angles) between start and end of the task.

**Sample size**

A convenience sample of 27 patients post-stroke was taken from an ongoing large prospective cohort study. In addition, 10 age- and gender-matched healthy controls were also additionally included in this study.

**Statistical methods**

The R studio (commander) (version 1.4.1103) was used for analyzing the data. Data were assessed for normal distribution using the Shapiro-Wilk test. Mean and standard deviation were used to summarize shoulder flexion and average velocity and median and interquartile range were used to summarize skewed data of time, shoulder extension, elbow flexion and elbow extension. One-way ANOVA was used to calculate between-group differences for normally distributed variables such as shoulder flexion and average velocity. Kruskal Wallis test was done to analyse between-group differences for non-normally distributed variables namely, time, shoulder extension, elbow flexion and elbow extension. We also performed the Bonferroni’s post-hoc test to determine individual between group differences. Effect sizes were determined using Cohen’s d. Formula used to calculate effect size was as follows:

\[ \theta = \frac{\mu_1 - \mu_2}{\sigma} \]

Where, \( \theta \) is effect size, \( \mu_1 \) and \( \mu_2 \) are the two-group sample means and \( \sigma \) is their pooled standard deviation. Effect sizes were reported by interpreting Cohen’s d as small (0.20-0.50), medium (0.51-0.80) or large (>0.8) effect.\(^26\) The level of significance was set at ≤0.05 for all analyses.

**Results**

We included a total of 27 stroke survivors who were categorized into mild (n=9), moderate (n=10) and severe (n=8) categories based on the FM-UE scale. 10 age and gender matched healthy controls were also included as a control group. Demographic characteristics of all participants such as age, gender, affected limb, stroke type, presence of active hand movement at stroke onset, post-stroke duration and SAFE score are displayed in Table 3.

As shown in Table 3, out of 27 patients with stroke, 9 had a mild stroke, 10 had a moderate stroke and 8 had a severe stroke. Both, patients with stroke and healthy controls did not differ in the age range (p=0.2). The kinematic characteristics of stroke survivors and healthy controls have been compared and shown in Table 4.
As seen in Table 5, we observed a significant difference between all assessed kinematic variables, except shoulder flexion, namely time, average velocity, elbow flexion, elbow extension and shoulder extension across all four groups. The variable of time was found to be significantly different between the severe stroke group and all other groups, namely mild (d=-2.37, t=-4.9, p<0.001, df=33), moderate (d=-2.04, t=-4.31, p<0.001, df=33) and healthy controls (d=3.13, t=-6.6, p<0.001, df=33). This depicts maximum magnitude of difference between severe stroke survivors and healthy controls for the parameter of total time taken to complete the task. Participants across all the three stroke groups exhibited a prolonged duration for completing the task.

Average velocity was also significantly different between all the three stroke groups, namely mild (d=-1.36, t=2.98, p=0.03, df=33), moderate (d=-1.99, t=4.45, p<0.001, df=33) and healthy controls (d=3.13, t=-6.6, p<0.001, df=33). This depicts maximum magnitude of difference between severe stroke survivors and healthy controls for the parameter of total time taken to complete the task. Participants across all the three stroke groups exhibited a prolonged duration for completing the task.

Range of motion deficits were noted across all stroke groups in terms of shoulder and elbow flexion and extension angles, in comparison to healthy controls.

Elbow flexion was found to be significantly different between moderate and severe stroke groups (d=1.74, t=3.68, p=0.009, df=33) as well as between severe stroke group and healthy controls (d=1.83, t=3.86, p<0.001, df=33). The variable of elbow extension showed significant differences between mild and moderate stroke groups (d=0.25, t=0.54, p<0.001, df=33) as well as between healthy controls and all three groups of stroke namely mild (d=0.02,}

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**Table 3. Demographic characteristics of stroke survivors and healthy controls (n=37).**

<table>
<thead>
<tr>
<th>Participant characteristics</th>
<th>Healthy controls (n=10)</th>
<th>Stroke survivors (n = 27)</th>
<th>Mean±SD/n (Percentage)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Healthy controls (n=10)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (in years)</td>
<td>57.2±10.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gender (M: F)</td>
<td>6 (60): 4 (40)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Stroke survivors (n = 27)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>FM-UE categories</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mild (n=9)</td>
<td>59.7±10.4</td>
<td>52.6±13.4</td>
<td>65.5±8.9</td>
</tr>
<tr>
<td>Moderate (n=10)</td>
<td>56.5±7.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Severe (n=8)</td>
<td>62.5±10.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>6 (66): 3 (33)</td>
<td>7 (70): 3 (30)</td>
<td>5 (62.5): 3 (37.5)</td>
</tr>
<tr>
<td>Gender (M: F)</td>
<td>3 (33): 6 (66)</td>
<td>8 (80): 2 (20)</td>
<td>4 (50): 4 (50)</td>
</tr>
<tr>
<td>Affected limb (R: L)</td>
<td>7 (77): 2 (22)</td>
<td>7 (70): 3 (30)</td>
<td>7 (87.5): 1 (12.5)</td>
</tr>
<tr>
<td>Post-stroke duration (days)</td>
<td>4.4±0.7</td>
<td>4.2±1.1</td>
<td>4.4±1.5</td>
</tr>
<tr>
<td>SAFE score</td>
<td>6.3±1.3</td>
<td>3.8±1.9</td>
<td>4.1 (2.1, 2.4)</td>
</tr>
<tr>
<td>FM-UE score</td>
<td>56±6.5</td>
<td>33.4±3.4</td>
<td>13.8±9</td>
</tr>
</tbody>
</table>

**Table 4. Comparison of kinematic variables between stroke survivors (n=27) and healthy controls (n=10) using ANOVA analysis.**

<table>
<thead>
<tr>
<th>Variables (units)</th>
<th>F</th>
<th>df1</th>
<th>df2</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>18.4</td>
<td>3</td>
<td>13.7</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Average velocity</td>
<td>32.9</td>
<td>3</td>
<td>17.4</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Shoulder flexion</td>
<td>1.51</td>
<td>3</td>
<td>16.3</td>
<td>0.25</td>
</tr>
<tr>
<td>Shoulder extension</td>
<td>9.66</td>
<td>3</td>
<td>16.5</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Elbow flexion</td>
<td>2.96</td>
<td>3</td>
<td>16.0</td>
<td>0.064</td>
</tr>
<tr>
<td>Elbow extension</td>
<td>5.83</td>
<td>3</td>
<td>17.0</td>
<td>0.006</td>
</tr>
</tbody>
</table>

As seen in Table 5, we observed a significant difference between all assessed kinematic variables, except shoulder flexion, namely time, average velocity, elbow flexion, elbow extension and shoulder extension across all four groups. The variable of time was found to be significantly different between the severe stroke group and all other groups, namely mild (d=-2.37, t=-4.9, p<0.001, df=33), moderate (d=-2.04, t=-4.31, p<0.001, df=33) and healthy controls (d=3.13, t=-6.6, p<0.001, df=33). This depicts maximum magnitude of difference between severe stroke survivors and healthy controls for the parameter of total time taken to complete the task. Participants across all the three stroke groups exhibited a prolonged duration for completing the task.

Average velocity was also significantly different between all the three stroke groups, namely mild (d=-1.36, t=2.98, p=0.03, df=33), moderate (d=-1.99, t=4.45, p<0.001, df=33) and healthy controls (d=3.13, t=-6.6, p<0.001, df=33). This depicts maximum magnitude of difference between severe stroke survivors and healthy controls for the parameter of total time taken to complete the task. Participants across all the three stroke groups exhibited a prolonged duration for completing the task.

Range of motion deficits were noted across all stroke groups in terms of shoulder and elbow flexion and extension angles, in comparison to healthy controls.

Elbow flexion was found to be significantly different between moderate and severe stroke groups (d=1.74, t=3.68, p=0.009, df=33) as well as between severe stroke group and healthy controls (d=1.83, t=3.86, p<0.001, df=33). The variable of elbow extension showed significant differences between mild and moderate stroke groups (d=0.25, t=0.54, p<0.001, df=33) as well as between healthy controls and all three groups of stroke namely mild (d=0.02,
Table 5. Bonferroni (post-hoc) test for comparison of kinematic variables between stroke survivors (n=27) and healthy controls (n=10).

<table>
<thead>
<tr>
<th>Kinematic variables (units)</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
<th>Healthy controls</th>
<th>p value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (sec)</td>
<td>6.87 (6.4, 7.91)*</td>
<td>9.75 (31.3, 40.6)*</td>
<td>15.7 (12.4, 42.9)*</td>
<td>4.73 (4.42, 4.83)</td>
<td>&lt;0.001 *</td>
</tr>
<tr>
<td>Average velocity (m/sec)</td>
<td>0.37±0.14*</td>
<td>0.3±0.09*</td>
<td>0.13±0.08*</td>
<td>0.51±0.06</td>
<td>&lt;0.001 *</td>
</tr>
<tr>
<td>Shoulder flexion (°)</td>
<td>37.03±12.3</td>
<td>11.33±3.4</td>
<td>0.18±1.2</td>
<td>10.02±3.2</td>
<td>0.09</td>
</tr>
<tr>
<td>Shoulder extension (°)</td>
<td>9.8 (9.13, 14.3)*</td>
<td>10.1 (9.93, 12.8)*</td>
<td>-1.92 (-3.22, 3.55)</td>
<td>22.9 (15.2, 34.5)</td>
<td>&lt;0.001 *</td>
</tr>
<tr>
<td>Elbow flexion (°)</td>
<td>102 (96.9, 113)*</td>
<td>110 (106, 117)*</td>
<td>64.4 (31.2, 107)*</td>
<td>123 (108, 125)</td>
<td>0.02 *</td>
</tr>
<tr>
<td>Elbow extension (°)</td>
<td>141 (137, 142)*</td>
<td>148 (128.4, 149.2)*</td>
<td>170 (163, 177)**</td>
<td>118.68 (89.04, 127.3)</td>
<td>&lt;0.001 *</td>
</tr>
</tbody>
</table>

*ANOVA test of analysis.
Kruskal Wallis test.
\*p<0.001 between severe and mild, moderate and healthy controls.
\*p<0.001 between mild, moderate, severe and healthy controls.
\*p<0.001 between mild and severe stroke groups.
\*p<0.01 between moderate and severe stroke groups.
\*p<0.001 between severe stroke group and healthy controls.
\*p<0.001 between mild and moderate stroke groups.
\*p<0.001 between moderate and severe stroke groups.
t=-0.05, p<0.001, df=33), moderate (d=-0.22, t=0.5, p<0.001, df=33) and severe (d=-0.27, t=4.37, p<0.001, df=32) and healthy controls with moderate and severe groups showing equal effect sizes. We also observed significant difference between moderate and severe (d=2.35, t=4.95, p<0.001) stroke groups, where the moderate stroke group had more shoulder extension range compared to severe stroke group. Figure 4 depicts the between- and within-group differences for the kinematic parameters of time, shoulder flexion, average velocity, elbow flexion, elbow extension and shoulder extension across all three groups of stroke and healthy controls.

**Discussion**

A total of six kinematic variables namely, time, average velocity, elbow flexion, elbow extension, shoulder flexion and shoulder extension were assessed using a 3D kinematic analysis system, while performing a reach-to-grasp-to-mouth task. All kinematic variables except shoulder flexion, exhibited significant differences across all four groups.

The parameter of time was found to be significantly different between the severe stroke group and all other groups. The participants in the severe stroke group took more time to perform the task compared to mild and moderate stroke groups and healthy controls which either could be because of increased initiation time or due to reduced interjoint coordination. This finding was similar to a study in which mild and moderate stroke survivors (based on FM-UE scores) and healthy controls were recruited. It was reported that participants in the stroke group had slower movement times. This study also made use of 3D motion analysis for a standard drinking task; however, each participant performed only 5 trials as opposed to 20 trials in our study.27 Another study with a task slightly different than ours such as the timed finger-to-nose test also reported that the time required for completing the task was longer in stroke survivors as compared to controls. However, the task given to the participants was a timed finger-to-nose test and the included participants were chronic stroke survivors, which was in contrast to our more functional reach-to-grasp-to-mouth task that was performed by sub-acute stroke survivors.18 Another study with similar findings included a group of chronic stroke survivors and a
comparatively less functional task such as the nine-hole peg test. They also reported that the stroke group participants had prolonged timings to complete the task and they attributed it to the significantly reduced dexterity in stroke survivors. As a result of this, the stroke group was observed spending a longer time in the grasping and releasing phases of the nine-hole peg test.28

Considering the parameter of average velocity to be a derivative of time, we observed that it was significantly different between all three stroke groups and healthy controls as well as between mild and severe stroke groups. Similar findings were exhibited by all three previous studies, in which they reported that stroke survivors demonstrated significantly lower peak speed or peak velocities compared to healthy controls.18,27,28

Prolonged task durations and a resulting decrease in velocity, can be attributed to various underlying reasons. Firstly, the stroke survivors find it difficult to initiate a movement. Secondly, as a result of weakness related incoordination and developing synergy patterns, they might take a long duration of time to accurately attempt reaching and grasping the target. Thirdly, the lack of interjoint coordination leads to difficulty in controlling the movement in order to bring the hand back to the starting position. Additionally, we also encounter easy fatigability in stroke survivors while performing a task. Hence, as they progress to more repetitions, they tend to take a comparatively longer duration to complete the task with every recurring movement.29

Along with kinematic parameters of time and average velocity, we have also reported comparisons of shoulder and elbow range of motion (ROM) between as well as across the four groups. We noted that both shoulder and elbow extension showed significant differences across all stroke groups and healthy controls. Additionally, elbow extension was found to be significantly decreased in the moderate stroke group in comparison to the mild stroke group. The stroke survivors in the severe group were found to exhibit a mean elbow extension angle of 10° throughout the task. The starting position of the task was 0° of elbow extension. Hence, this depicts that the severe group of stroke patients were only able to move the elbow through 10° of flexion. This could be attributed to plausible maximal weakness of both the triceps as well as the biceps in comparison to other stroke groups as well as healthy controls. Similarly, for shoulder extension, we considered a starting neutral position of the shoulder joint at 0°. Thus, shoulder flexion angle increased as the task progressed from the starting position to reaching-to-target and reaching-to-mouth phases. This was followed by a reversal of the movement to bring the UE back to its starting position. As a result of this, we observed a relative shoulder extension to bring the shoulder back to neutral. Thus, healthy control participants were seen to demonstrate maximum shoulder extension when compared to all stroke groups. On the contrary, participants in the mild stroke group demonstrated maximum shoulder flexion, but did not exhibit maximum shoulder extension. This could be because participants with stroke experience difficulty in bringing the shoulder back to its starting position, perhaps, because of poor eccentric control of shoulder flexion in addition to spasticity.

Elbow flexion was significantly different in severe versus moderate stroke survivors and healthy controls. Stroke survivors tend to exhibit tonal abnormalities along with weakness, which could result in active ROM deficit especially at the shoulder and elbow joints.

A review article encompassing research in the area of UE kinematic analysis in individuals with stroke also reported that reduced elbow extension and shoulder flexion was frequently described as alterations of movement patterns across numerous studies.30 The same studies, which carried out 3D motion analysis of a drinking task27 and that of the finger-to-nose test18 also reported deficits in elbow flexion and extension angles in stroke survivors.

Out of all the reported kinematic variables in this study, time and average velocity were best able to distinguish between healthy controls and severely affected stroke participants as evidenced by their respective effect sizes. The findings of this study provide us with an objective method of kinematic assessment, which can be used in future longitudinal cohort studies to potentially distinguish between varying groups of stroke survivors with different severity levels such as mild, moderate and severe, based on the FM-UE scores, as well as healthy controls.

One limitation of this study is that we have not carried out follow-up assessments for the recruited stroke participants. Longitudinal assessments of these kinematic parameters up to 3 and 6 months would be a valuable addition to gaining information regarding post-stroke recovery. However this study is part of an ongoing large longitudinal cohort study in which we have assessed all kinematic parameters at 1 month and outcomes such as FM-UE and ARAT at three months for building prognostic models that can predict post-stroke motor recovery at three months.

We would also recommend future researchers to plan similar long-term longitudinal cohort studies that would reflect upon the time related responsiveness of kinematic metrics in individuals with stroke. It could further help in
distinguishing across the various recovery mechanisms post-stroke by exploring differential movement patterns across
different groups of post-stroke recovery. Additionally, spasticity is also known to have a profound effect on the recovery
post-stroke. It would hence be beneficial to objectively measure spasticity using well-established methods such as the
Montreal spasticity measure that determines the tonic stretch reflex threshold.31 This method can be used as an effective
bedside measure of post-stroke spasticity in future studies investigating UE kinematic parameters post-stroke.

**Conclusion**

Kinematic parameters of time, average velocity, elbow flexion, elbow extension and shoulder extension for a reach-to-
grasp-to-mouth task help to differentiate between varying groups of severity post-stroke such as mild, moderate and
severe, based on FM-UE scores as well as from healthy controls. This ability to differentiate across stroke severity groups
would enable us to objectively quantify post-stroke recovery and help in realistic goal setting and planning rehabilitation.

**Data availability**

**Underlying data**

Harvard dataverse. Dataset for kinematic analysis.xlsx. DOI: [https://doi.org/10.7910/DVN/EIK0VY](https://doi.org/10.7910/DVN/EIK0VY)

This project contains the following underlying data:

Dataset for kinematic analysis.xlsx (This dataset comprises of participant data for 27 stroke patients and 10 healthy
control participants. The participants have been analyzed for upper extremity kinematic parameters such as “total
movement time, average velocity and shoulder and elbow flexion and extension angles”. The stroke patients have been
analyzed against the healthy participants for all of these kinematic parameters.).

Data are available under the terms of the Creative Commons Zero “No rights reserved” data waiver (CC0 1.0 Public
domain dedication).

**STROBE checklist**

Harvard dataverse Replication data for: STROBE checklist.docx. DOI: [https://doi.org/10.7910/DVN/VFZZGR](https://doi.org/10.7910/DVN/VFZZGR)

Replication data for: STROBE checklist.docx (This file comprises of table depicting The Strengthening the Reporting of
Observational Studies in Epidemiology (STROBE) Statement: guidelines for reporting observational studies”.

Data are available under the terms of the Creative Commons Zero “No rights reserved” data waiver (CC0 1.0 Public
domain dedication).

**Software availability**

Software used in this study: MATLAB © 2020

The kinematic raw data in this project has been analyzed using a software code that was tailor-generated by the team to
deduce the final kinematic parameters of total movement time, average velocity and shoulder and elbow flexion and
extension angles

- Archived source code at the time of publication (DOI) for the software code in Zenodo. DOI: 10.5281/zenodo.7971415
- Octave version of software Zenodo DOI: 10.5281/zenodo.8033608
- GitHub Repository [KINEMATIC_ANALYSIS.m](https://github.com)
- Octave Online Bucket

Software is available under the terms of the “Creative Commons Attribution 1.0 Generic”
References


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