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RESEARCH ARTICLE

Kinematic analysis in reaching activity for hemiparetic stroke subjects using simplified video processing method

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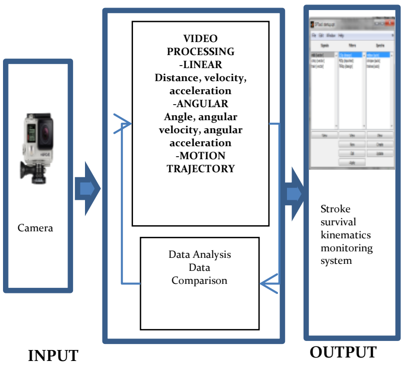
Graphical abstract



Abstract

The purpose of this study is to compare and analyse the trajectory and the kinematic variables (displacement, velocity, acceleration) of reaching activity of the upper limb part of hemiparetic stroke patient from normal side and affected side using a low cost video processing method. The research is conducted in three different categories which are recovering, half recovery and non-recovery stroke patient group. Six subjects were divided equally in the respective categories and they performed three trials for each reaching task, the trial was conducted by a qualified physiotherapist while the subjects were sitting on a straight-back chair or on their wheel chair. A GoPro video cameras were used to record the reaching movement in two dimensional perspective and from the recorded video, the comparison analysis was done and evaluated based on the maximum, mean and the standard deviation, kinematics performance and reaching trajectory. With this technique, was achieved implement a system that allows viewing kinematic variables as which detected in the cycle of reaching gait. The results showed a significant different between these three group and were consistence with those reported in the literature.

Keywords: Kinematic, hemiparetic stroke, video processing

INTRODUCTION

Human motion analysis was one of the interesting fields in medical engineering and showed a promising prospect in the coming era, this was due to the baby boomers era during the 40s and 60s (Jones., 2009) were entering their retirement phase and now become aging population. Various health problem starting to occur within the population, most of the health problem related to stroke, joint and muscle problem and the health issues affected their lifestyle performance and worse, it also affected their normal Activity of Daily Living (ADL) (Darin *gg*., 2016).

Reaching was one of the basic ADL tasks, difficulty to perform reaching was a significant post-stroke problem. It was found that 70% to 75% of survivors demonstrated limitations in reaching and a further 20% of survivors were not able to move the upper limb at all. Reaching was a typical functional arm movement and requires multi-joint coordination in completing activities of daily living (Chang *et al*., 2008). Previous studies have examined the reaching kinematics of normal, Parkinson's disease and stroke subjects. These kinematic studies in reaching performance had found that subjects with movement disorders have an increased movement duration, decreased velocity, increased segmentation and increased variability in path trajectory. In addition, subjects with a movement disorder significantly show less smooth and continuous path trajectory when reaching for an object with higher accuracy constraints (Cheung *et al*., 2009).

A study was conducted showing that alterations in muscle activation were present in hemiparetic subjects regardless of lesion location, the initial level of motor severity (Wagner *et al*., 2007), or time since the initial assessment of stroke. While muscle onset times were delayed in the hemiparetic group, the prime movers of the reaching task which were anterior deltoid and biceps brachii were activated prior to the start of the movement (Arnold et al., 2010), to initiate the reach. In contrast, muscle onset times of the wrist extensors and flexors occurred after the start of movement at the acute time point. The delay in muscle onset times for wrist extensors and flexors may reflect greater deficits in the neural control of the distal upper extremity musculature, where the influence of the corticospinal system was the greatest. Kinematic pattern analysis in previous studies had been done in various ways. Most studies used wearable inertial sensor, VICON 3D optical motion capture system and others either in healthy individuals or stroke patient, which were relatively an expensive equipments. Marker placement used for all devices in previous study mostly had common anatomic locations which are indexed fingertip, distal ulnar head (wrist), lateral epicondyle (elbow), ipsilateral and contralateral acromion processes (shoulders) and sternal angle (Chang *et al*., 2008).

There were many kinematics variables which can be utilized to reflect the characteristics of reaching. While reaching for an object, stroke patients with moderate motor impairment showed irregular path profiles along with more movement corrections in the in reaching. A previous study found that there were significant correlations between reaching kinematics, which are peak velocity, the number of movement unit and normalized jerk score of movement and level of motor impairments (Chang *et al*., 2008). A study done by (Wagner *et al*., 2007) reported that reaching the performance of the acute hemiparetic group was generally poor, such that the hemiparetic group had lower peak speeds, larger endpoint errors and less efficient movements compared to the healthy control group.

MATERIALS AND METHOD

The objective of the research is to develop a non contact technique to asses the stroke patient reaching activity, to reduce the treatment and assessment time for the stroke patient with a less painful method. The subject assessment was approved by UKM research ethics committee PPI/11-JEP-2016-410 under the human ethic protocol.

Materials

Kinematic data were measured from six stroke patient subjects age between 55 to 65 years old and their movement were captured as they performed the reaching activity using two GoPro video cameras. Subjects were divided into 3 groups, Group 1 was for stroke patient that were already recovered, Group 2 was for stroke patient that can move their upper limb part of their own, but not yet fully recovered (weak muscle) and for the Group 3 was for stroke patient that cannot move their upper limb part of their own, but being supported by their non-affected part. Subjects were placed with an attachable five sensor (also as a marker) at the dedicated upper limb joint, the five point location was sufficient to measure kinematic parameters for stroke patient (Messier *et al*., 2006 & Massie *et al*., 2012). The subject demography data can be referred in Table 1.

Table 1 Demography data for reaching test subjects.

Subject	Age	Sex	Duration of stroke (years)	Condition
001	55	F	3	Group 1:
002	58	F	2	Recovery
003	61	F	5	Group 2:
004	63	M	4	Half Recovery
005	65	M	6.5	Group 3:
006	63	F	4	Non Recovery

Protocols

Subjects were asked to perform a forward reaching task while seated in a straight-back chair or in their wheel chair. Their trunk will be stabilized to the back of a chair to minimize compensatory trunk movements, the shoulder was in approximately 0° flexion, extension and internal rotation and the elbow were in 75° to 90° flexion, with the wrist rested palm down, and the finger joints in slight flexion of their thigh.

Table 2 Phase movement definition.

Phase	Activity	Detect by
(1) Rest Position	Hand position were horizontal with the target object	Velocity value will be zero
(2) Move Forward	Hand begin to move towards the target object	Velocity value will positively increased
(3)Reaching target	Hand will reach the target object and stop for 1 second	Velocity value will be zero/nearly zero
(4) Move Backward	From the target object hand will move back ward to rest position	Velocity value will negatively decreased
(5) Rest Back	Hand position were horizontal with the target object	Velocity value will be zero

The starting, reaching and ending position of the event can be determined based on the velocity measurement reading. The starting of the activity position was determined when then velocity increased from $0ms^{-1}$ value, the reaching position was determined when the value of the velocity was decreased to $0ms^{-1}$ and the reverse movement was determined by the increased value of the velocity. The ending of the movement was determined when the velocity decreased to $0ms^{-1}$value. The phase definition for each movement can be referred in Table 2 and Figure 1a. The position of the marker on the subjects for the reaching activity was shown in Fig 1b.

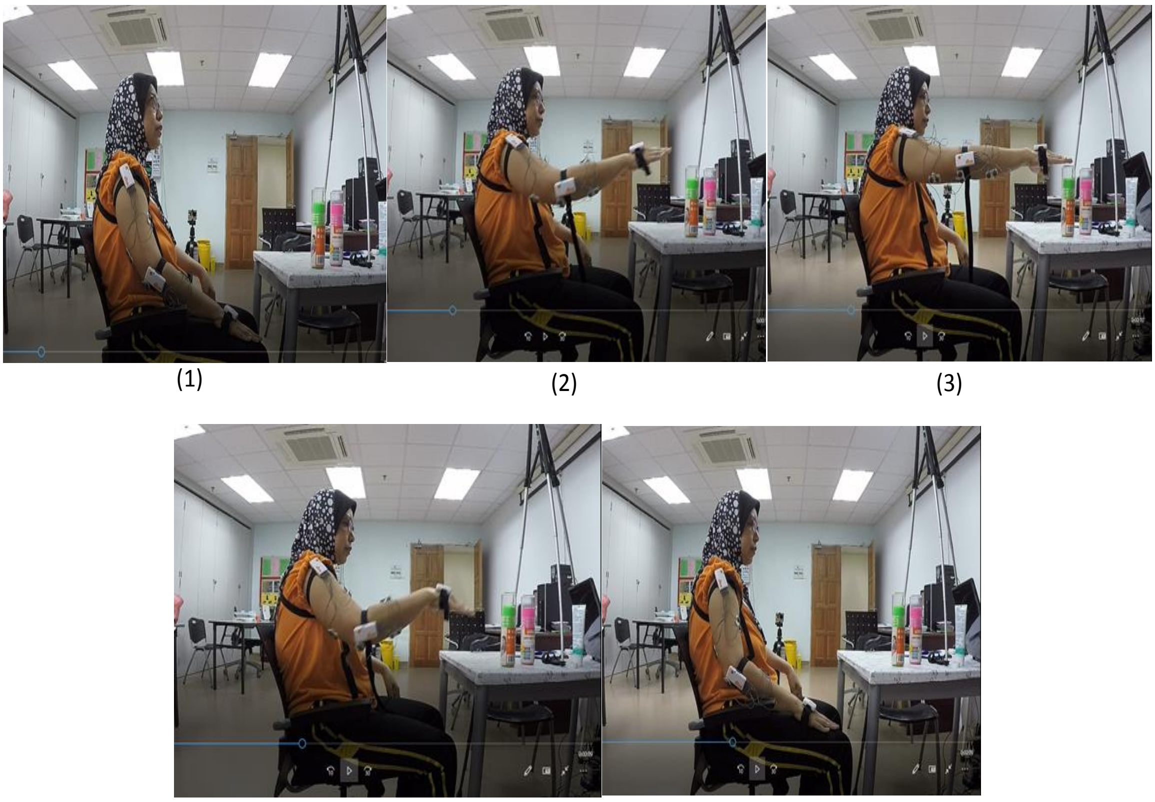
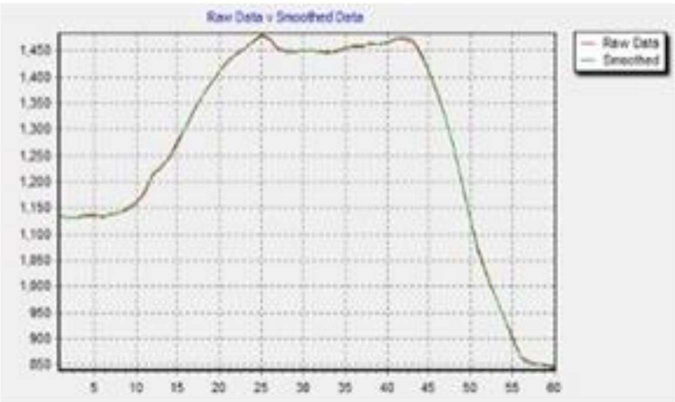


Figure 1a Reaching movement phase.

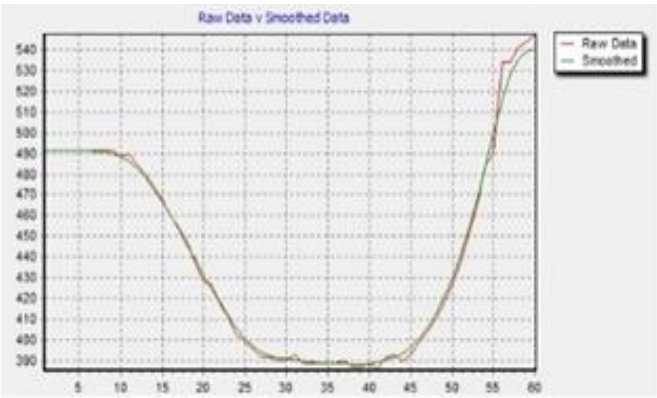
Fig 1b (a) Position of the wearable sensor (marker) and (b) reaching task activity.

Minor modifications such as increased shoulder internal rotation at the start position were allowed for some subjects to minimize any positional discomfort. Subjects were then being instructed to reach forward and touched a cylinder target positioned 90% of arm's length directly in front of the affected and the dominant shoulder at shoulder height.

Subjects were given one or two practice trials prior to familiarize themselves with the task and the instructions. Three trials of reaching movement were recorded, data collection was limited to three trials only due to the reason hemiparetic subjects can easily feel the fatigue and to prevent the subjects from having stress issue when performed the task.



X-Axis



Y-Axis

Fig 2 Data smoothing using the moving average method.

Instrumentation and video recording

Cylinder object size 20cm × 5.5cm was used for the reaching as a target object, the cylinder was also used as a calibration reference (length measurement) for the reaching activity. GoPro Video Camera was used to capture the motion of the subject performing the reaching action with camera setting of 60 frames per second (fps) to ensure the sufficient video motion data for the subject. Two video cameras were placed on the left and the right side between the subject position.

Quintic biomedical software was used to track linear velocities, accelerations and the angular rotations based on the track markers that were attached along the upper limb at scapula, shoulder, elbow, wrist and fingertip.

Data analysis and signal processing

The two dimensional data values (X and Y axis for each marker) were filtered using three points moving average method for marker trace data smoothing. Since the trace of the marker were manually plotted based on video observation, it should be filtered to minimise the error by a using simple and efficient method. The data were resample using three points moving average method (Limin Sun et. al.,2016). The original tracking was marked by the red line and the filtered tracking were marked by the green line as shown in Fig 2.

The marker positions represented in a virtual way in two dimensions perspective, and by plotting on each frame sequentially, the trajectory of biomechanical models of segment for each marker can be developed. A set of 1280 x 700 pixels at 60 fps is used because current capability for normal video camera. By increasing at higher frequency, better video quality can be obtained, but requires more computational and resources to process video file. The results are obtained by which calculates the position values, performing arithmetic difference of the angles generated. Based on the position and sampling frames, the kinematic values were obtained.

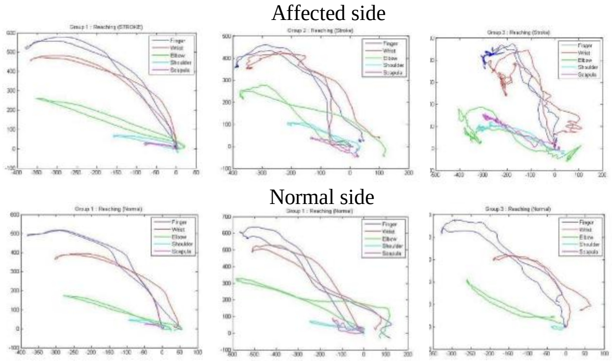
RESULTS AND DISCUSSION

At the end of the test, all the subjects were managed to perform three reaching trials and complete the reaching movements. The result from reaching activity were seperated into three parts for analysis. There are movement travelling trajectory, linear analysis and statistical analysis.

Movement travelling trajectory

The movement travelling trajectory pattern was manually plotted on the X and Y axis point to point based on the 60 fps video image marker movement. The analysis aim was to compare the pattern between the stroke and normal side and also between each group as shown in Fig 3.

Affected side



Group 1 Group 2 Group 3

Fig 3 Reaching trajectory pattern.

For the Group 1 trajectory travelling pattern, can be deducted that there was slightly small different pattern between the stroke side with the normal side pattern, on the normal side, reaching trajectory movement was shorter and more minimise, both of the pattern was smooth and have less distortion. The trajectory for finger and the wrist (upper graph) on the affected subject travel in a similar pattern, this was suspected due to the affected finger were still stiff, rigid and the subject cannot release their fingers when reached the cylinder object which make the trajectory for wrist and finger travelled in a similar way.

Group 2 showed more significant differences in trajectory pattern between the affected and normal side. The finger, wrist and elbow travelled by a long way and in an unstable movement, there was a ripple pattern can be seen through the movement and at the peak of the movement which mean that the affected side has lack of muscle control once their hand reached the cylinder object. This also suspected due to their strength and flexibility of their muscle has been reduced after having a stroke (Shaiful & Gan, 2017).

The differences in the travel pattern in Group 3 were more obvious, the stroke travelled in an unstable condition from the beginning and ripple pattern increased once the subjects reach the cylinder object. It means that the stroke patient does not have the ability to control smoothly the affected side using their own normal side upper limb. This was suspected due to the movement of their affected part were more stiff, smaller range of motion and have higher resistance.

Kinematic Analysis

There were three kinematics variables being analysed through the reaching activity evaluation, which were displacement, velocity and acceleration as showed in Fig 4, Fig 5 and Fig 6 respectively. The graph colour indicates the position of the marker which were indigo (finger), blue (wrist) yellow (elbow) green (shoulder) and red (scapula).

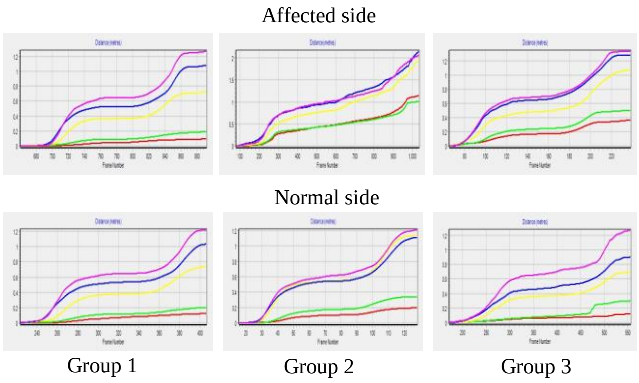


Fig 4 Displacement graph between each group for reaching activity.

The total travel distance for the Group 1 was 4.81m (normal) and 3.78m (affected side), total travel distance for Group 2 was 5.89m (normal) and for 5.04m (affected) and total distance for the Group 3 was 12.2m (normal) and 5.27m (affected side), the total travelling distance was increased from the Group 1 to Group 2 and the Group 3. There were differences between the normal and affected side, total travel distance for normal side was lower than the stroke side, this was suspected due to the range of motion for the stroke side was smaller and the movement was limited due to the muscle stiffness.

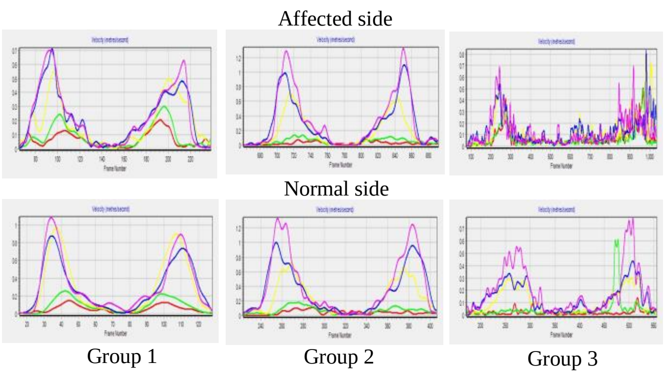


Fig 5 Velocity graph between each group for reaching activity.

The graph presents the pattern of the velocity against time. The pattern was quite similar between the affected and the normal limb for the Group 1 and Group 2, but there are significant difference in the velocity pattern aspect of the Group 3. There are more ripple peaks on the affected part from the beginning of reaching activity. This might due to the subject cannot control the movement of their own and the ripple part occurred in the affected part when they tried to against the movement supported from the normal side.

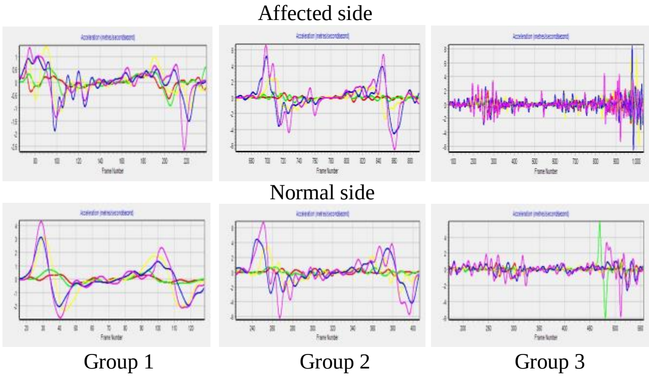


Fig 6 Acceleration graph between each group of reaching activity.

The acceleration pattern between the three groups showed a significant difference between Group 2 and Group 3. This may due to the acceleration of normal side was smoother as participant has clear visual information when to accelerate and decelerate when performing the reaching movement that synchronised with the brain order. As for the affected side, there was a resistance from the affected muscle and the acceleration and deceleration process was restricted physically. For the Group 1, both acceleration showed a similar pattern for normal and affected side.

Table 3 Max, means and standard deviation for linear analysis.

Kinematic			Group 1	Group 2	Group 3
Distance	**Stroke**				
(m)		Max	1.42	1.34	2.16
		Min	0.36	0.47	0.74
		Stdv	0.16	0.13	0.13
	Norm				
		Max	1.36	1.21	1.25
		Min	0.30	0.39	0.31
		Stdv	0.16	0.15	0.14
Velocity	**Stroke**				
(ms^{-1})		Max	1.46	0.71	0.5
		Min	0.30	0.15	0.28
		Stdv	0.18	0.24	0.00
	Norm				
		Max	1.88	1.08	0.87
		Min	0.36	0.194	0.01
		Stdv	0.22	0.12	0.07
Acceleration	**Stroke**				
(ms^{-2})		Max	8.70	1.39	8.42
		Min	0.01	0.01	0.00
		Stdv	1.11	0.19	0.30
	Norm				
		Max	8.59	4.28	4.85
		Min	0.04	0.00	0.00
		Stdv	1.62	0.55	0.36

Statistical analysis results were conducted and shown as in Table 3. Three statistical variables which were maximum, means and standard deviation values were reported. For the travelled distance, Group 1 showed shorter movement (min 0.36 m/0.30 m) and Group 3 showed longer movement (0.74 m/0.31 m). Group 1 showed a larger variation of the data set with standard deviation of 0.16. This is due to fact that the range of motion for Group 1 was larger compared to the other two groups. In terms of velocity, Group 1 used the fastest route (min 0.3 ms^{-1}/0.36 ms^{-1}) with maximum velocity of 1.46 ms^{-1}/1.88 ms^{-1}. It showed that the Group 1 has better velocity control over the other two groups. Group 1 accelerate faster with (min 0.01 ms^{-2}/ 0.04 ms^{-2}) with maximum acceleration of 8.70 ms^{-2}/8.59 ms^{-2} compared with other two groups

CONCLUSION

This study showed that the efficiency of reaching movement performance were ranked from Group 1 > Group 2 > Group 3. It's based on the movement efficiency (shorter movement time), straight movement travelling pattern (less total displacement and travelling distance), smooth movement (velocity and acceleration), stability (lower standard deviation for displacement and velocity) and optimisation of movement (high angular value). This finding is in accordance with those reported by previous literature (Subramaniam *et al*. 2010).

The result suggests that the kinematic parameters can be used for stroke rehabilitation progress monitoring. It can be served as a base for kinematic performance improvement among the stroke survivor. This is a non contact method that provides a convenient monitoring and less painful method for the stroke survivors.

The study also showed the difference in the pattern between normal and affected side movement from kinematic point of view. This provides a better understanding of characteristic of the stroke patient reaching movement. For the further study, it is suggested that the experiment can be conducted simultaneously with the electromyogram (EMG) sensor to measure the muscle strenght that associated to the kinematic variables.

The method used in this work is a simple, economic and reliable procedure that can be used to obtain kinematics parameters of the joints for the stroke patient. It also has a potential to be widely used in the other biomechanic area and can be combined with other sensor such as electromygram to be used for muscle force prediction (Gianfranco, 2010) .

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