MEKATRONIKA
JOURNAL OF MECHATRONICS AND INTELLIGENT MANUFACTURING
E-ISSN: 2637-0883
VOLUME 6, ISSUE 1, JANUARY 2024, 44 – 52
DOI: https://doi.org/10.15282/mekatronika.v6i1.10181

RESEARCH ARTICLE

Performance Characteristics of Stroke Patients using the Motor Activity Log and ANOVA Analysis

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ABSTRACT - Scoring system is crucial in evaluating a patient's stroke severity and monitoring their recovery progress. The current manual and subjective approach heavily rely on the therapist's individual expert, resulting inconsistent in scores and increased burden on the therapist's workload. This pilot study aims to automate and refine the scoring methodology utilised for stroke patient's assessment. This study focuses on Motor Activity Log (MAL), a widely acknowledged standard clinical assessment that incorporates the evaluation of Activities of Daily Living (ADL) in stroke patients. Data are collected from 30 healthy individuals and 30 stroke patients. Two statistical analyses using one-way ANOVA are performed to check the data characteristics and assess the effectiveness of the MAL in this context. The analysis results indicated two scores that did not show significant differences, specifically 0.328 for the Rotation X parameter in the Doorknob activity and 0.587 for the Time parameter in the Water Faucet activity. This demonstrates that this test method can effectively differentiate between each stroke patient. This initiative represents a significant step towards establishing a more standardised and objective scoring system, contributing to a more consistent and efficient evaluation of stroke patients' performance characteristics and recovery trajectories.

ARTICLE HISTORY
Received : 28th Jan 2024
Revised : 20th April 2024
Accepted : 28th April 2024
Published : 3rd May 2024

KEYWORDS
Activity of Daily Living
ANOVA Analysis
Motor Activity Log
Occupational Therapy
Stroke Rehabilitation

1.0 INTRODUCTION

A stroke is a sudden interruption of blood flow to a specific part of the brain, causing the death of brain cells [1][2]. Over 13.7 million stroke episodes occurring annually emerged as a significant global concern. The three main types of strokes are transient ischemic attack (TIA), ischemic stroke, and hemorrhagic stroke, which exhibit distinct characteristics [3-6]. TIA entails a brief halt in blood supply to the brain, serving as a warning sign for potential future strokes. Ischemic stroke, accounting for approximately 87% of all strokes, occurs when a blood vessel supplying the brain is obstructed [7], while hemorrhagic stroke occurs when a blood vessel ruptures [3]. This understanding creates the urgency of addressing strokes as a crucial public health issue.

An efficient rehabilitation treatment to restore motor function in stroke patients is highly necessary, looking at the increment in the number of stroke patients [8]. The rehabilitation treatment for post-stroke patients is accompanied by motor function assessment routinely performed manual by the therapists in deciding the subsequent intervention that will be provided to the patients [9]. The manual assessment or quantification of patients' capability suffers from numerous problems. It is highly subjective and relies heavily on the therapist's experiences [10]. To restore the subjects' upper limb functional ability and reduce the costs of treatment and health care, current research has converged towards more effective treatment methods by taking advantage of technological developments instead of traditional rehabilitation therapy [10–12].

Technological developments have been utilised to encourage subject involvement in rehabilitation therapy. It has the potential to allow multiple training sessions and evaluate the subject's performance throughout the recovery session [12]. Substantial evidence is that training on intensive movements with many repetitions can improve rehabilitation results, either in each stage of rehabilitation or long-term treatment. Several strategies to offer technology assistance have been developed in the recent past [14][15].

A pilot study has been conducted to enhance the scoring methodology utilised for stroke patients, which is crucial for evaluating the severity of stroke patient's and monitoring their recovery progress. To achieve this objective, the Motor

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Activity Log (MAL), a widely recognised standard clinical assessment incorporating the Activity of Daily Living (ADL) for the evaluation of stroke patients, is employed. The MAL assessment comprises several versions, including MAL-30, MAL-45, MAL-12, MAL-14, MAL-26, and MAL-28 [16]. All activities within these MAL versions are directly associated with ADL. Consequently, two activities are carefully selected, given their prevalence in nearly all MAL versions, the necessity for mastering activities essential for daily living and the ability to strategically place sensors on these ADLs to capture the required parameters. The chosen activities are "turning a doorknob" and "turning water on/off with knob/lever on a faucet."

Based on the literature review, the evaluation of stroke patients hinges significantly on the quantification of both the force exerted by the patient and the time required to accomplish specific tasks. Consequently, these two parameters are documented while subjects engaged in chosen ADL and the data are collected in conjunction with other relevant parameters identified as related to strengthen this pilot study. A comprehensive explanation regarding the parameters recorded, the appropriate sensors employed and the data logger used will be elaborated upon in Section 2: Experimental Setup. The collected data comprises two groups of subjects: 30 healthy individuals selected randomly from the Machinery Technology Centre of SIRIM Berhad in Rasa, Selangor, and 30 stroke survivors from Sultan Ahmad Shah Medical Centre (SASMEC) IIUM in Kuantan, Pahang. Approval for the data collection from stroke patients is obtained from the IIUM Research Ethics Committee (IREC) under the ID number IREC 2023-078. All subjects are provided with the opportunity to practice the selected ADLs before their data are recorded to mitigate potential recording errors. Additionally, subjects were requested to repeat each ADL three times to ensure the precision of the recorded data. Further details on data processing will be explained in Section 3: Data Analysis. The remaining sections of this paper are structured as follows: Section 4 presents the results and discussion of the analysis, offering insights into the findings, examining the calculated outcomes from the collected data. Finally, Section 5 concludes the overall work in this paper, summarising key insights and potential for future research.

2.0 METHODS AND MATERIAL

Two selected ADLs from the MAL assessment are "turning a doorknob" and "turning water on/off with knob/lever on a faucet", extracted from the MAL assessment standard. Force Sensing Resistor (FSR) type of force sensors are employed to capture force parameter readings for both ADLs, offering measurements in Newtons for the applied force. The FSR force sensors are attached to both ADLs. Meanwhile, a data logger integrated with the ESP32 microcontroller is utilised for the time parameter, featuring a sampling time of 500 microseconds.

The capturing of equipment motions is crucial to demonstrate the completion of the ADL task. In the case of the Doorknob, high effectiveness is achieved using a Time-of-Flight (ToF) VL53L0X ranging sensor. Readings within the 0mm to 15mm range, where 0mm indicates no rotation of the knob and 15mm corresponds to a complete turn of the knob. Besides, for Water Faucet, a 360-degree rotary encoder sensor is employed for monitoring the water faucet lever's rotation.

The subsequent set of parameters to be captured involves the movement of the subject's hand. Considering both ADLs require hand movements, the recording of the subject's hand movement is integrated to support the upcoming calculations. The measurement of rotation in both the X and Y direction is facilitated by employing the MPU6050 3-axis acceleration gyroscope module. Housed in a box and secured with a strap to emulate the wearing of a wristwatch, this sensor ensures the subject's comfort and avoids any discomfort to the subject caused by electronic equipment. A great feature of this sensor is its ability to simultaneously record hand movements in two directions. Figure 1 shows the directions of recorded hand movement in X and Y rotation.

Moving forward, the coordination of all these sensors is efficiently managed by the ESP32 Wrover B. This compact device ensures centralised control and boasts a sizeable range of capabilities. The ESP32 Wrover B is incorporated with Wi-Fi functionality, providing a gateway for potential Internet of Things (IoT) applications. This strategic inclusion allows for seamless connectivity and communication, opening up possibilities for remote monitoring, data analysis and other IoT-related functionalities that may deemed valuable. The ESP32 Wrover B is a versatile and robust central hub, facilitating the integration and synchronisation of various sensor data while laying the foundation for broader and more sophisticated applications as technological needs evolve.

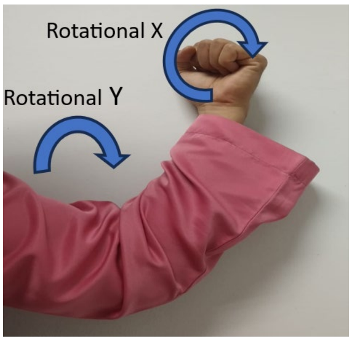


Figure 1. The directions of hand movement in X and Y rotation

The designated ADL equipment is fixed to a rigid board and positioned on a table. An adjustable seat is provided during the data collection to allow the subjects to do these activities comfortably. Before data recording, subjects are encouraged to familiarise themselves with the ADL tasks through trial sessions. However, it's important to acknowledge that not every subject is inclined or suitable for these trials. In the case of healthy subjects, these activities often align with their daily routines and many of them do not express keen interest in trial sessions. On the other hand, individuals recovering from a stroke may experience fatigue during these attempts. Consequently, trial opportunities are offered to subjects who exhibit genuine interest and are appropriate for such sessions. This approach ensures a tailored and considerate technique to the ADL assessments, recognising the diverse capabilities and preferences of the participating subjects.

Three test sessions are programmed for each activity. However, it's important to note that not all stroke subjects can complete all three test sessions due to their limitations. The readings are recorded using a data logger. The collected data is organised systematically for analysis. Any data during the rest periods are excluded, ensuring precision and accuracy in the experimental analysis. By focusing exclusively on the movement parameters during the execution of the activity, this study provides insight into the subject's performance and capabilities, contributing to a comprehensive understanding of their functional abilities and potential areas for improvement.

3.0 DATA ANALYSIS

The data logger records several parameters during the activities, which are the maximum force applied, the range of hand movement in X and Y rotation, the ADLs motion and the time taken to complete the activity. Three readings are taken for each activity to ensure its accuracy. The average values are used for subsequent analysis. This approach provides a comprehensive and representative assessment of the subject's performance, minimising the influence of potential outliers for a more reliable result.

The MAL score measures stroke patients' functional abilities and movement quality. It comprises Amount of Use (AOU) and Quality of Movement (QOM). Certified SASMEC therapists conduct assessments to determine the MAL score. Each stroke patient is assigned to therapists who work closely with them to ensure a deep understanding of their needs and evaluate their progress. These therapists' expert and familiarity with their patients contribute to the reliability of the MAL score assessments. The therapists' close interactions with their patients and continuous involvement in rehabilitation enable them to provide standard evaluations while considering each stroke patient's unique needs, challenges and improvements. This approach enhances the overall quality of the MAL score. A therapist’s professional judgment provides accurate representation of the patient's functional abilities and movement quality.

The organised data's characteristics have been analysed using one-way ANOVA with IBM SPSS Statistics 27 software. The analysis of character data involves comparing the following:

1. Analysis (i): The data between healthy subjects and stroke patients who scored 5, which is the same as pre-stroke for AOU and normal for QOM.
2. Analysis (ii): The input parameters for AOU and QOM score ranging from 1 to 5, with 1 corresponding to very rarely for both AOU and QOM, 2 corresponding to rarely for both AOU and QOM, 3 corresponding to half of pre-stroke for AOU and fair for QOM, 4 corresponding to ¾ of pre-stroke for AOU and almost normal for QOM, and 5 corresponding to the same as pre-stroke for AOU and normal for QOM.

For Analysis (i), it is hypothesised that there won't be any significant difference, which will be indicated by a p-value is more than 0.05 ($p > 0.05$). This hypothesis is based on the MAL assessment, where a score of 5 should align with a healthy subject or normal condition, even if they had previously experienced a stroke. As for Analysis (ii), the hypothesis is a significant difference, with a p-value lower than 0.05 ($p < 0.05$) occurred for AOU and QOM parameter input. This expectation is based on the perception that each MAL score level should exhibit parameter readings that have a significant difference. The data analysis requires excluding subjects with a score of 0 due to identified inconsistencies in their data.

In the first step of analysis, each input and output parameter are normalised using the Min-Max normalisation method as defined by the formula [6][7];

$$X_{Normalised} = \frac{X - X_{Min}}{X_{Max} - X_{Min}} \quad (1)$$

where X denotes the current value, X_{Min} represents the minimum value within the dataset and X_{Max} signifies the maximum value within the dataset. The leading purpose of normalisation is to standardise all data points to a shared scale; [0,1], streamlining the comparison and analysis process [22].

The data collection, restructuring and normalisation processes are executed utilising Microsoft Excel software. Following this, the data are transferred to IBM SPSS Statistics 27 software in the following procedure.

Step 1

All normalised data are subsequently pasted into the Data View tab.

Step 2

For Analysis (i), modifications are required in the Variable View tab, where the Name column is adjusted to Status to differentiate between stroke or healthy, Force for the input force parameter, X for the Rotation X input parameter, Y for the Rotation Y input parameter and Time for the input time parameter, in accordance with the data arrangement in the Data View tab. The data type is indicated in the Type column, with the default setting placing the data type as Numeric. All data are left at the default setting since all inputs are numeric type inputs, except for Status, which needed to be changed to String according to its data type, i.e., healthy or stroke. In the Value column, everything is left at the default setting except for Status. H was used for healthy subjects and S for stroke patients. These symbols needed to be declared in this column. The Measure column is the last to be modified. In the Status line, the default scale setting needed to be changed to Nominal, following the data type. Apart from that, the settings are left at the default setting. The Variable View tab related to the Doorknob activities for Analysis (i) is shown in Figure 2. This analysis excludes the consideration of ADLs motion, AOU and QOM, focusing solely on subjects with a full score.

Step 3

The Analyze tab at the top of the window is selected and the General Linear Model option is chosen.

Step 4

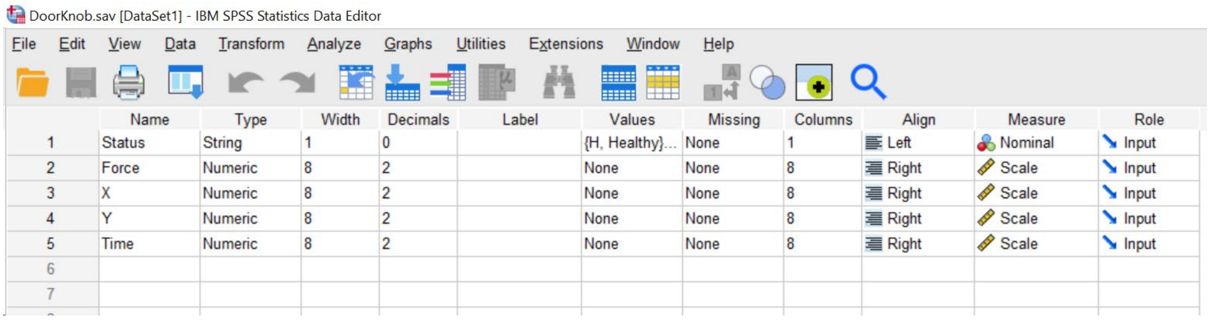
The option for Univariate to initiate the One-Way ANOVA process. In the ensuing dialogue box, designate "Status" as the Fixed Factor and "Force" as the Dependent Variable, aligning with the specifications depicted in Figure 3. The tabs such as Model, Contrast, and others positioned on the right side serve the purpose of configuring the ANOVA output settings, providing flexibility for customisation based on specific requirements.

Step 5

Once the configuration is complete, proceed by clicking the OK button.

Step 6

The analysis process continues by substituting the Dependent Variable with "X" for Rotation X, "Y" for Rotation Y and "Time" for input time. The same method is applied to both activities and both ANOVA analyses.



	Name	Type	Width	Decimals	Label	Values	Missing	Columns	Align	Measure	Role
1	Status	String	1	0		{H, Healthy}...	None	1	Left	Nominal	Input
2	Force	Numeric	8	2		None	None	8	Right	Scale	Input
3	X	Numeric	8	2		None	None	8	Right	Scale	Input
4	Y	Numeric	8	2		None	None	8	Right	Scale	Input
5	Time	Numeric	8	2		None	None	8	Right	Scale	Input
6											
7											

Figure 2. Variable View tab pertaining the Doorknob activities for Analysis (i)

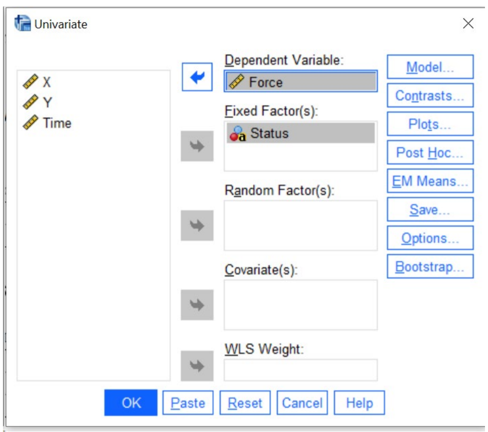


Figure 3. Univariate dialog box for Analysis (i) data

4.0 RESULTS AND DISCUSSION

Analysis (i) has been conducted on the data of healthy subjects and stroke patients who scored 5; equivalent to pre-stroke conditions for AOU and normal conditions for QOM. In this scenario, a total data of 45 respondents for the ADL Doorknob and 44 respondents for the ADL Water Faucet have been selected for this analysis. The results of One Way ANOVA for this data can be seen in Tables 1 and 2. Out of these, 30 respondents are healthy subjects, while the rest are stroke patients. This analysis aims to assess the equivalence between the two groups of subjects as hypothesised. Therefore, parameters such as Motion, AOU, and QOM are excluded from consideration because all recorded values for these parameters are uniform 5. This approach ensures that the analysis is tailored to highlight and support the hypothesised equivalence between stroke patients with a score of 5 and healthy subjects.

The obtained results significantly deviate from the hypothesis. In the case of ADL Doorknob, marked differences are revealed in the parameters of Force, Rotation Y and Time. Only the Rotation X results do not show a significant difference, supporting the hypothesis. A similar situation occurs with the ADL Water Faucet data, where the analysis of parameters Force, Rotation X and Rotation Y shows significant differences. However, no significant difference is observed in the Time parameter; follow the hypothesis. Nevertheless, this incongruity aligns seamlessly with the findings of the literature review, consistently indicating that overall healthy subjects tend to be outperformed by stroke patients, even when assigned an equivalent score of 5 across all parameters. Furthermore, these findings confirm the appropriateness of the selected ADLs, where the obtained data can still differentiate between healthy subjects and stroke patients scoring 5.

Table 1. Analysis (i) ANOVA analysis on Doorknob activity

Parameter	P Value	Conclusion
Force	0.001	Significant different
Rotation X	0.328	No Significant different
Rotation Y	0.029	Significant different
Time	0.031	Significant different

Table 2. Analysis (i) ANOVA analysis on Water Faucet activity

Parameter	P Value	Conclusion
Force	0.001	Significant different
Rotation X	0.018	Significant different
Rotation Y	0.048	Significant different
Time	0.587	No Significant different

Subsequently, both activities are analysed based on their estimated marginal means using three significant datasets, as depicted in Figure 4 and Figure 5 for Doorknob and Water Faucet, respectively. As indicated by the data means, the application of Force reveals that healthy subjects apply stronger pressure than stroke subjects. This finding aligns with the literature review, where the stroke patients generally demonstrate weakened strength compared to their healthy counterparts. The analysis of the Time required for both ADLs is also consistent with the literature review, indicating that stroke subjects take a longer time to perform ADLs compared to healthy subjects. Since this data collection also focuses on hand movement as the input parameter. It is observed that stroke patients engage in a larger movement than healthy subjects to complete the same given activity. Based on observations, stroke patients appear to employ different techniques by executing more steps in carrying out ADLs compared to healthy subjects. The characterisation of hand movements, to the best of the author's knowledge, has not yet been documented in any literature review.

The findings of Analysis (ii) are presented in Tables 3 and 4. The analysis involved a sample of 60 participants, consisting of 30 stroke patients and 30 healthy individuals, for both ADLs. This analysis aims to investigate the characteristics of the input data recorded for each individual. A One-way ANOVA is conducted to test the hypothesis that there would be a significant difference in the scores assigned to each participant. Data with a score of 0 were excluded from the analysis due to inconsistencies observed, rendering it unreliable for analysis.

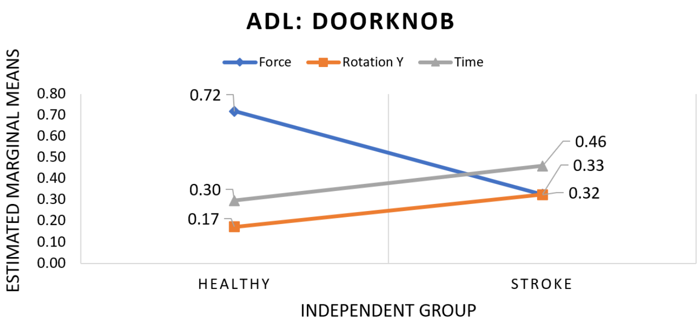


Figure 4. Estimated marginal means for Doorknob activity

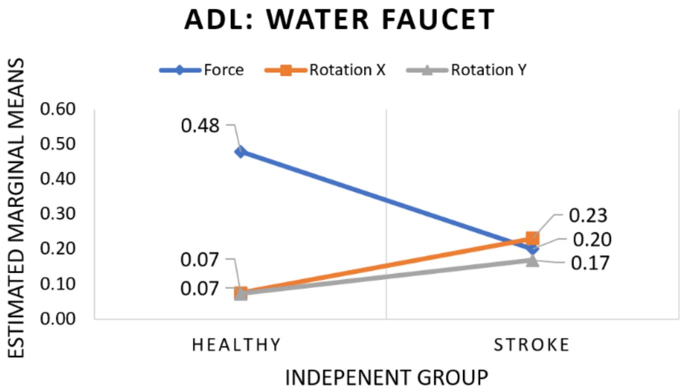


Figure 5. Estimated marginal means for Water Faucet activity

Table 3. Analysis (ii) ANOVA analysis on Doorknob activity.

Parameter	p Value for AOU	Conclusion	p Value for QOM	Conclusion
Force	0.001	Significant different	0.001	Significant different
Rotation X	0.001	Significant different	0.031	Significant different
Rotation Y	0.001	Significant different	0.001	Significant different
Motion	0.001	Significant different	0.001	Significant different
Time	0.001	Significant different	0.001	Significant different

Table 4. Analysis (ii) ANOVA analysis on Water Faucet activity.

Parameter	p Value for AOU	Conclusion	p Value for QOM	Conclusion
Force	0.168	No Significant different	0.014	Significant different
Rotation X	0.002	Significant different	0.001	Significant different
Rotation Y	0.001	Significant different	0.001	Significant different
Motion	-	-	-	-
Time	0.001	Significant different	0.001	Significant different

Based on the result presented in Table 3, the ANOVA analysis conducted for the Doorknob activity showed a significant difference in scores, which is consistent with the hypothesis and validates the test's appropriateness. Moving on to Table 4, the ANOVA analysis for the Water Faucet activity has also demonstrated a significant difference, except for the analysis between Force input and AOU output. However, even though the significance value was 0.168, it can still be considered slightly significant and the results remain acceptable. For the ADLs motion, ANOVA analysis could not be performed because all respondents who scored between 1 and 5 are able to complete this activity.

The analysis has been done with estimated marginal means using significant datasets, as depicted in Figures 6 to 9. Referring to Figure 6, the estimated marginal means for the Doorknob activity in relation to its AOU output reveal that the Force parameter indicates equivalent mean for scores 1 and 2, that is 0.23. Subsequently, there is an increase for scores 3, 4, and 5, reaching 0.64 at score 5. The Motion parameter, representing the Doorknob and Water Faucet motion, also shows an increase between scores 1 and 2. For scores 3, 4, and 5, the mean achieved at the highest level, 1, indicating successful activity completion. The hand movement parameter, represented by Rotation X and Y, exhibits a different trend. The marginal mean for Rotation X indicates the highest means at score 2, while the lowest mean is observed at score 3. However, the overall means show a decreasing trend. Similarly, for Rotation Y, the lowest readings are recorded at score 3. However, overall estimated marginal mean indicates a decreasing trend from score 1 to 5. Observing the Time parameter, estimated marginal mean show a consistent decreasing trend across scores.

Figure 7 illustrates the estimated marginal mean for the Doorknob activity to its QOM output. A nearly similar trend is observed, where the estimated marginal mean for the Force parameter generally shows an increasing trend across scores, although there is a slight decrease at score 3; 0.27. The trend for Motion reading is also upward from scores 1 to 3, reaching its maximum value at scores 4 and 5. Rotational X mean exhibit a decrease from score 1 to 3, with score 3 being a turning point where the mean increase again at scores 4 and 5. In contrast to Rotational Y, its estimated marginal mean decreases from score 1 to 3 and slightly increase at score 4, only to decrease again at score 5. Furthermore, for the Time parameter, the estimated marginal means consistently show a declining trend from score 1 to 5.

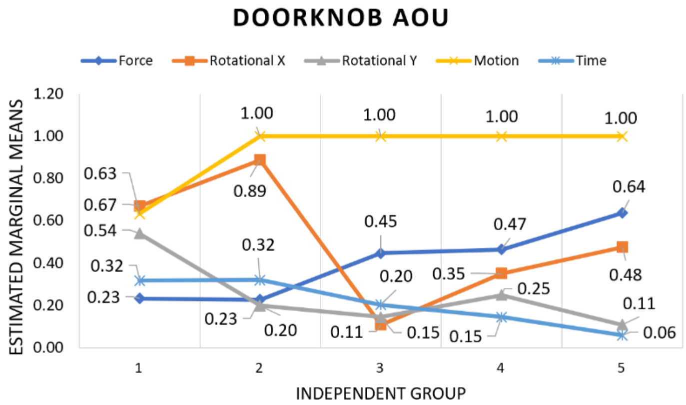


Figure 6. Estimated marginal means for Doorknob activity to its AOU

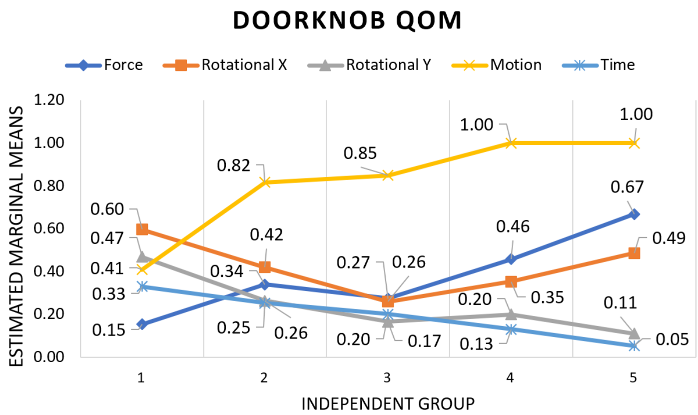


Figure 7. Estimated marginal mean for Doorknob activity to its QOM

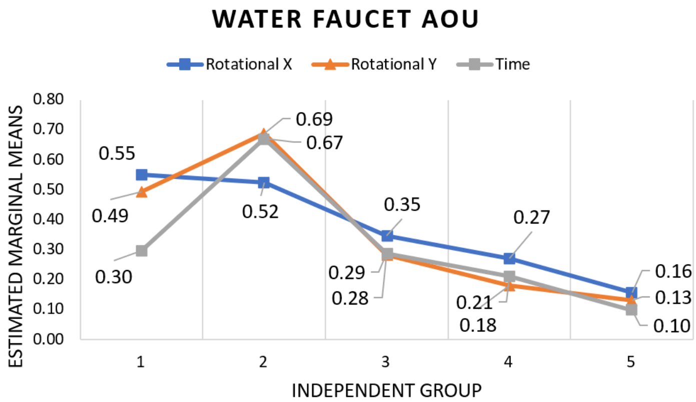


Figure 8. Estimated marginal mean for Water Faucet activity to its AOU

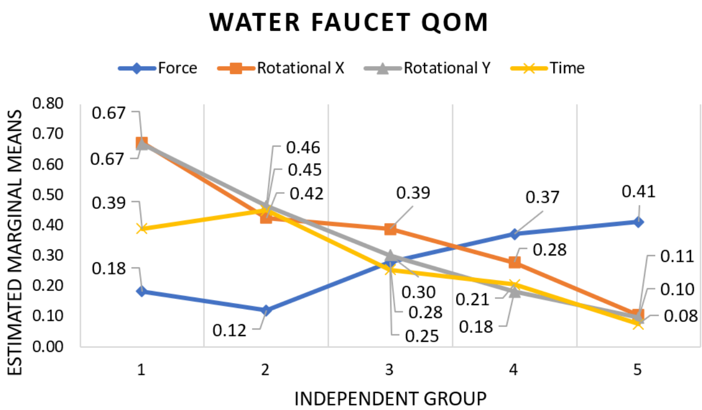


Figure 9. Estimated marginal mean for Water Faucet activity to its QOM

Figure 8 describes the graph of estimated marginal mean for significant differences of the Water Faucet activity with its AOU output. Three parameters exhibit significant differences: Rotational X, Rotational Y, and Time. Force does not show significant differences, with a p-value more than 0.05; 0.168. The ANOVA analysis cannot be conducted on the Motion parameter since all subjects completed the activity. Estimated marginal mean for the Rotational X parameter indicates a decreasing trend across the scores. On other hand, for Rotational Y, the estimated marginal mean slightly increases from 0.49 for score 1 to 0.69 for score 2 before following a decreasing trend to 0.13 at score 5. The estimated marginal mean for the Time parameter shows a pattern almost identical to Rotational Y, with an increasing trend at scores 1 and 2, i.e., 0.3 and 0.67, followed by a decrease for scores 3, 4, and 5, reaching 0.10 at scores 5.

Figure 9 presents the graph for estimated marginal means for the ADL Water Faucet activity to its QOM output. All parameters show significant differences in ANOVA analysis, except for the Motion parameter, where the test could not be conducted as all subjects completed this ADL. The Force parameter indicates a decrease from 0.18 to 0.12 for scores 1 and 2. However, its estimated marginal mean continues to increase steadily, reaching 0.41 at score 5. Conversely, a contrasting trend occurs in the estimated marginal mean for the Time parameter. There is a slight increase at scores 2 from score 1, and subsequently it decreases to 0.08 at score 5. Hand motion, represented by the Rotational X and Y parameters, also shows a similar trend of decline from 0.67 at score 1 to 0.11 for Rotational X and 0.10 for Rotational Y at score 5.

In general, the estimated marginal means graph for the Force parameter indicates an increasing trend across scores, suggesting that as the subject's score increases, the pressure applied to the ADL equipment to complete the activity becomes stronger. In contrast, the Time parameter graph shows a decreasing trend, meaning that as the subject's score increases where they end the activity faster. The general trend indicates a decline across scores for hand movement parameters represented by Rotational X and Y. This suggests that healthier subjects require less movement to complete ADLs. The estimated marginal mean analysis for the Motion parameter, specifically for the Doorknob activity, shows an increasing trend across scores. However, tests could not be conducted for the Water Faucet activity because all subjects can fully complete the activity.

5.0 CONCLUSION

This paper discusses the findings from a pilot study on the Analysis Performance Characteristics of Stroke Patients using the Motor Activity Log (MAL) and ANOVA Analysis. Two Activities of Daily Living (ADL), Doorknob and Water Faucet have been selected from the MAL assessment and employed for data collection. The data from 60 subjects, comprising 30 stroke patients and 30 healthy subjects are gathered for this pilot study. The force, encoder and IMU sensors installed on the ADL devices and the subjects' hands to obtain input parameter readings. The output parameters; AOU and QOM are the scores collected from certified therapists.

Two ANOVA analyses indicated that Force and Time parameters are crucial for assessing the stroke level or the progress of stroke patients' recovery. The ADLs motion parameter seemed less helpful for the analysis process, but it remains important for evaluating the extent to which a subject successfully completes ADL tasks. Furthermore, a significant finding from this pilot study is the hand motion parameter, revealing that stroke patients at a lower level exhibit more movement compared to healthier individuals.

Based on the findings, further research needs to be conducted. Given the positive ANOVA results, scores such as AOU and QOM can be derived through calculations using normalisation functions, supervised machine learning, and other methods. These results could be incorporated as one of the assessment methods in hospitals and rehabilitation centres, enhancing traditional subjective assessments with a more objective and consistent approach which may allow for home-based rehabilitations.

The ADL can also be expanded according to MAL assessment, transforming it into a kit for stroke patients. With this innovation, it is anticipated that stroke patients will not only benefit from an objective assessment but also utilise it as an exercise tool throughout the recovery period.

6.0 ACKNOWLEDGEMENTS

The authors thank the Ministry of Higher Education (MoHE) Malaysia for funding the research under grant number FRGS/1/2021/TK0/UIAM/02/10. Furthermore, we would also like to acknowledge Sultan Ahmad Shah Medical Centre (SASMEC) for allowing us to collect data at their Rehabilitation Centre.

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