International Journal of Engineering Trends and Technology
ISSN: 2231 – 5381 /doi:10.14445/22315381/IJETT-V69I4P205
Volume 69 Issue 4, 27-33, April 2021

Physical Factors Investigation on Surgical Dexterity Parameters Using Computer-based Assessment System

Y.K. Cham[#1], E. L. M. Su [#2], C.F. Yeong[*3], S.N.Z. Ahmmad[%4], S. Sood [^5], A. Gandhi [^6]

[#] *School of Electrical Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia.*

[*] *Centre of Artificial Intelligence and Robotics (CAIRO), Universiti Teknologi Malaysia, Johor Bahru, Malaysia.*

[%] *Malaysian Institute of Industrial Technology, Universiti Kuala Lumpur, Bandar Seri Alam, Johor Bahru, Malaysia.*

[^] *Faculty of Medicine, Jeffrey Cheah School of Medicine and Health Sciences, Monash University, Johor Bahru, Malaysia.*

[1] yingkit@graduate.utm.my, [2] eileensu@utm.my, [3] cfyeong@utm.my

Abstract — *Surgical dexterity is one of the crucial metrics for evaluating candidates during surgical residency training. Many factors influence surgical dexterity performance, but they are not studied in depth. Hence, the objective of this study is to investigate the correlation between factors and surgical dexterity performance with the aid of a computer-based assessment system. A custom data acquisition module was developed, namely the "Green Target Module," to acquire positional data of hand movements from the subjects when controlling a cursor in a 3D virtual reality (VR) scene. The positional data were recorded and extracted into seven objective parameters, which are motion path length, the economy of movement, motion smoothness, motion path accuracy, motion path precision, endpoint accuracy, and endpoint precision. Body posture, magnification, and handedness were investigated to figure out a preferable setup for better performance. A total of thirty-four subjects from different surgical backgrounds were recruited for the experiments. Fourteen trials were recorded in each test, and every subject was required to complete eight tests with different experimental configurations. Results showed that endpoint accuracy while sitting was significantly better than standing. Using 10x magnification during surgical dexterity assessment showed significantly better performance outcomes than 1x magnification. Performing dexterity test using dominant hand also showed significantly better when compared to non-dominant hand.*

Keywords— *Manual dexterity; assessment parameters; assessment factors; body posture; visual magnification; handedness.*

I. INTRODUCTION

Surgery is an inevitable treatment for some medical cases such as tumor removal [1], tissue reconstruction [2], and even removal of acute blockage from blood vessels [3]. A surgeon's technical knowledge and dexterity are important to ensure a successful surgical outcome.

Many factors could affect the surgical performance, such as lighting and layout of the operating room [4], the surgical facilities, physical movement, and human personalities. Some journals highlighted that discomfort and fatigue due to the body postures while performing procedures [5]. Besides, the use of a microscope [6] and even the ambidextrous skills during the surgery would affect the way they operate, there would have a risk that could endanger the patients, and it costs a life if it is not handling seriously. With current technology, there were many solutions proposed by using sensors with computational unit supports to objectively evaluate the motion performance [7]–[9].

In this study, a computer-based assessment system was developed for assessing the surgical dexterity of subjects with varying body posture, magnification, and handedness during the experiment.

II. PREVIOUS WORKS REGARDING MANUAL DEXTERITY

Surgical dexterity was often assessed using a tweezer dexterity pegboard to train the surgical residents by transferring the pegs from a bundle space to a point differently [10]. Then, the pegs were required to be transferred back to their original place. Time taken was used for the assessment, yet it was not convincing to only use the time to assess surgical dexterity. Soap carving and knot tying were some skills assessments that can be evaluated visually, but it lacks objectivity in measurement. Additionally, it makes the assessment highly dependent on expert evaluation and their availability.

Some simulations were introduced to record hand movements and to imitate the surgery procedure by using force sensors attached to the hands. This was to investigate the force exerted by the surgeons[11], [12]. Besides, the hand movement of surgeons was tracked using electromagnetic sensors [13].

In recent years, many virtual reality simulations that worked with graphics and the haptic device could help the surgical residents to assess their surgical performance. Simulators such as DaVinci skills simulator (DVSS) from Mimic Technologies [14]–[16], Lap Mentor from 3D Systems [17], and others would help the surgical residents to train and assess their surgical skills. For instance, the time and the movement were recorded from all the trajectories, the global score was calculated from the simulators [18]–[20].

Although the performance of the surgeons can be assessed by using simulations, there are many factors that could affect manual dexterity. Body posture was one of the factors that might affect surgical performance. Researchers investigated and measured the discomfort of the muscles by using electromyography (EMG) sensors attached to the muscles, but the performance of the dexterity was not deeply evaluated [21].

Besides, the use of instrumentation such as microscopes or loupe could be one of the reasons that could affect surgical performance. According to Eichenberger *et al.*, the performance score from simulations showed that using a microscope could lead to better performance than without using the microscope. The evaluation was based on path length and the time taken off the trajectories [22].

There is a need to train ones' ambidexterity skills while performing the surgical skills as surgeons are required to manipulate different instruments using both their dominant and non-dominant hands while performing surgical procedures [23]. Elneel *et al.* investigated the performance of ambidexterity, but the parameters measured were using the total time taken, path length, and angular path of the trajectories [24].

It is crucial to investigate psychomotor performance throughout the surgical simulation tasks. According to Ahmad *et al*., several parameters could be used to measure psychomotor performance objectively using simulation software 'green target module' [25]. With all these assessment parameters, the author identified the performance was significantly different from the surgeon group and novice group. Yet, there were few constraints as the experiment was conducted only in a sitting position, using 10 times visual magnification and using the right hand to assess the surgical skills.

With these constraints, this study was proposed to further investigate the physical factors of body postures, visual magnifications, and handedness affect the surgical dexterity performance of the surgical subjects.

III. METHODOLOGY

In order to measure the manual dexterity of subjects objectively, the hardware was implemented, and the software was deployed in the assessment system that is similar to the work from Ahmmad *et al.* [25], [26]. Several changes were made to the experimental setups to investigate body posture, visual magnification, and handedness. A total of 34 subjects from different surgical backgrounds were recruited for this study. Before the experiment began, informed consent was required to be filled by the subjects, and subjects were required to follow the experimental protocol for collecting their manual dexterity corresponding to different experimental setups.

A. Hardware Implementation

The hardware used in this study included a display unit, an acquisition unit, and a computational unit. Acer 3D Monitor was used to display the graphics and for viewing purposes, whereas Sensable PHANTOM Omni haptic device was used to acquire the 3D positional data in real-time. Besides, Dell Alienware M17x was used as a computational unit for recording and saving the data from the acquisition unit.

For the display unit, Acer HS244HQ was chosen as it enabled the subject to view the graphics in 3D view with the aid of 3D shutter glass in-attached with IR transceiver. The 3D display unit uses frame-packing stereoscopic 3D, which allows subjects to estimate the depth of the object displays on the screen with three dimensions.

A pair of PHAMTOM Omni haptic devices were used to acquire 3D hand positional data in this study. In order to acquire the 3D positional data of the stylus tip at 1kHz iterations, the driver was installed, and the acquisition program was developed in the computational unit using the application programming interface (API) provided by 3DSystems (formally as Sensable Technologies). The haptic devices consist of digital encoders for positional and rotational sensing.

Dell Alienware M17x was used as a computational unit as it had the relevant graphic driver, nVidia GeForce 54m series, which provided a sufficiently fast rendering of virtual environment graphics to support 3D rendering for the 3D display. The computational unit also consisted of both HDMI and IEEE-FireWire ports which can connect to Acer HS244HQ 3D monitor for display purpose and interact with PHANTOM Omni haptic devices, respectively.

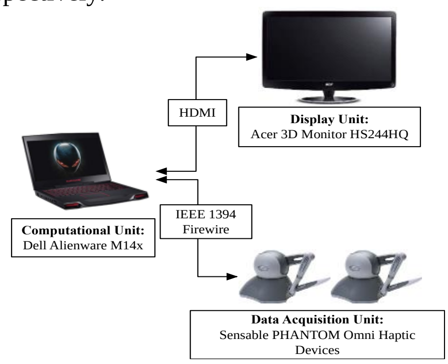

Fig. 1 Hardware Implementation

B. Software Integration

In this section, a customized assessment software was integrated into the computational unit to display the Graphical User Interface (GUI) on the 3D monitor and acquire surgical dexterity data from the subject using haptic devices. The assessment module named 'Green Target Module' was developed and modified to fit different experiment setups using Microsoft Visual Studio C++ in this study. The GUI was developed using Open Haptics and OpenGL libraries to acquire the real-world coordination from the haptic devices and draw the 3D virtual scene, respectively.

In Green Target Module, there were 7 target spheres, a purple starting sphere, and a pink cursor sphere on the virtual scene. With this module, the reaching trajectories from starting point to ending point and the pointing trials at the green targets could be investigated based on the different experimental setup.

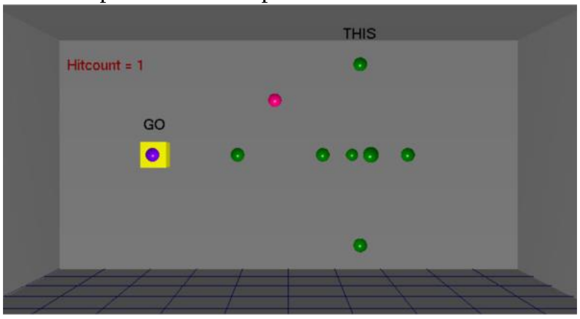

Fig. 2 Green target module

Before the trials started, the subjects were required to handle the PHANTOM Omni's stylus like holding a pen and be in the ready position. For reaching trajectories, the subjects could move the pink cursor from the purple color starting point to the target on the virtual scene by moving the PHANTOM Omni's stylus. Once the cursor reached the green target, the subject was required to hold the cursor at the target for 3 seconds, after which the green target would disappear, and the indicator 'NEXT' would be projected on the virtual scene to notify the subjects of the trials were successfully completed.

There was a total of 7 targets at different locations in Green Target Module, and the subject was required to complete two repetitions for each experiment configuration. Hence, a total of 14 trials were collected from the subjects for each experiment configuration.

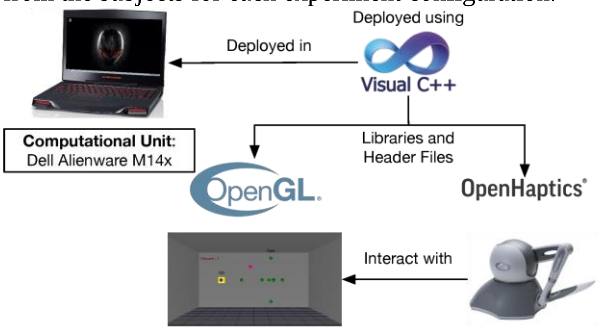

Fig. 3 Software integration

C. Experiment Setup

For the basic experiment setup, a table of 74 cm height was used throughout this study. In addition, two height-adjustable arm stands were given for supporting their arms to prevent fatigue and awkward position while performing the surgical dexterity assessment.

A total of three physical factors were investigated in this study, which were body posture, visual magnification, and handedness. All subjects were recruited and underwent eight different configurations with these three combinations of factors.

a) Body Posture

Two settings were investigated for body postures, namely, standing position and sitting position. For standing position, a station with two heights of 50 cm and 35 cm was used to increase the height of the display unit and the haptic devices, respectively. The arm stands were then adjusted to the level of the elbow height to give arm supports to the subject.

For sitting, the height of the seat was set to 44 cm, and the heights for both arm stands were lowered to the height of the table, depending on the comfort of the subjects.

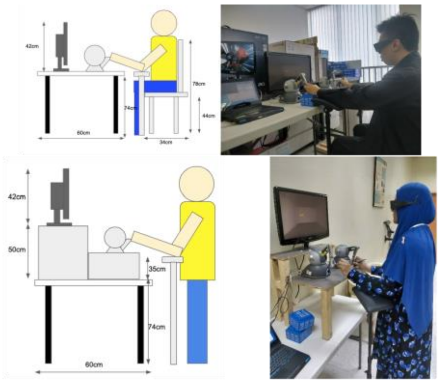

Fig. 4 Sitting and standing positions while performing the task

b) Visual Magnification

In this experiment setup, the visual display was configured to 1x or 10x magnifications in Green Target Module. According to Su *et al.*, significant error was found when comparing both 1x and 10x magnification for all subject groups, but no significant differences were found between 10x and 20x magnifications [27].

The magnification could be adjusted with software. When the computational unit received the acquisition data from the haptic devices, the positional data were then translated or magnified by 10 times before being displayed on cursor movements on the screen.

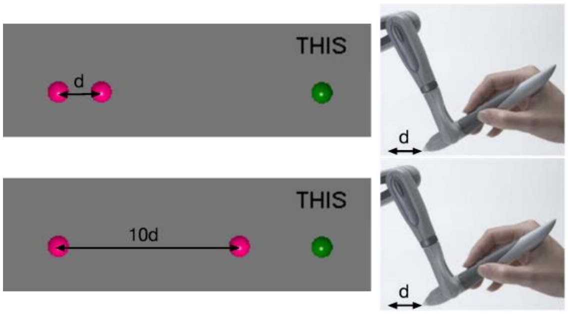

Fig. 5 1x (top) and 10x (bottom) visual magnifications.

c) Handedness

Handedness condition investigated the performance of dominant versus a non-dominant hand. Each subject performed sets of the experiment using their dominant or non-dominant hands to investigate the ambidexterity of the subjects by using a pair of haptic devices. For the right-handed subject, the right haptic device was used as dominant hand configuration, and the left haptic device as non-dominant hand configuration, and vice versa. During the experiment, only one hand was used, and the data were acquired from the hand, while the other hand was held still on another device. The experiment setup was implemented as a unimanual dexterity assessment.

D. Subject Demographics

A total of 34 subjects (female = 19, male = 15) aged between 26 and 55 years (average age 36 years) with different surgical backgrounds were recruited from two public hospitals in Malaysia. From the subject population, 33 subjects were right-hand dominant, and only 1 subject was left-hand dominant.

E. Protocol

Before the experiments began, the details of the nature and objective of the research were elaborated to the subjects, and informed consent was obtained from the subjects for granting permission on data collection. Besides, they were required to accomplish eight sets of experiments with three different physical factors: body posture, visual magnification, and handedness. The eight experimental configurations to be completed by a subject was as shown in the following list:

1. The subject performed an experiment at sitting posture, using 1x of visual magnification and using their dominant hand.
2. The subject performed an experiment at sitting posture, using 1x of visual magnification and using their non-dominant hand.
3. The subject performed an experiment at sitting posture, using 10x of visual magnification and using their dominant hand.
4. The subject performed an experiment at sitting posture, using 10x of visual magnification and using their non-dominant hand.
5. The subject performed an experiment at standing posture, using 1x of visual magnification and using their dominant hand.
6. The subject performed an experiment at standing posture,1x of visual magnification and using their non-dominant hand.
7. The subject performed an experiment at standing posture, 10x of visual magnification and using their dominant hand.
8. The subject performed an experiment at standing posture, 10x of visual magnification and using their non-dominant hand.

The sequence to complete eight sets of experiments was varied in this study to prevent learning curve and bias resulting from practicing in the same procedure for all subjects. The subject performed either in sitting or standing posture for the first 4 sets and the last 4 sets of experiments. In both 4 sets of the experiment, first two trials and the last two trials were using either 1x visual magnification or 10x visual magnification in the virtual scene. The first set and second set of experiments in all visual magnification sets of experiment were used either dominant hand or non-dominant hand in this study.

IV. OBJECTIVE PARAMETERS

After collecting all the trial data from the subjects, the motion data was then separated into dynamic trajectories and static motions. The dynamic trajectories were identified from the purple beginning point, reaching the target point. The dynamic motions were then analyzed into five parameters, which were motion path length, motion path accuracy, motion path precision, the economy of movement, and motion smoothness [26].

Motion path length was obtained by accumulating the distance passed through by the cursor from the purple starting point to the target throughout the reaching trajectories. For **motion path accuracy**, the mean error of motion deviated from the ideal path was identified. The ideal path was defined as the shortest path from the purple starting point to the green target, whereas **motion path precision** was obtained by computing the standard deviation of deviation from the ideal path. **Motion smoothness** was identified by counting the number of zero crossings from the acceleration profile. **The economy of movement** was calculated as the actual path divided by the ideal path from the depicted motions.

For static motion, the motions depicted after the cursor point had reached and hold to the target point for 3 seconds [26].

Endpoint accuracy was computed by obtaining the mean error of the cursor deviation from the endpoint target coordinate, whereas the **endpoint precision** was calculated by obtaining the standard deviation of the endpoint deviation throughout the 3 seconds pointing trajectories.

V. RESULTS

Before the data were grouped, the extracted parameters were normalized by individual subjects for identifying the factors that could affect the subject's performance during the assessment. There were three main categories in this study: body posture, visual magnification, and handedness. For body posture, the data were grouped into sitting and standing positions for the body postures. For visual magnification, the parameters were separated into a 1x magnification group and a 10x magnification group. For the handedness category, the parameters were separated into the dominant hand group and non-dominant hand group.

The normality for all the grouped data was examined using the Shapiro-Wilk test. In this study, all the grouped data were found to be the not normal distribution; therefore, Kolmogorov-Smirnov (KS) test was chosen for the non-parametric test because it compared continuous empirical distributions from both groups of data to examine the significant differences between them [28].

Tables I, II, and III show all the results obtained from the significant test. As indicated in Figure 6, all the dexterity parameters had insignificant differences except for normalized end-point deviation, showing that sitting position resulted in less endpoint deviation than standing position.

For visual magnification, significant differences were found between 1x magnification and 10x magnification in all dexterity parameters, as shown in Figure 7. The trajectories performed at 1x magnification showed significantly higher errors in most dexterity parameters than those performed at 10x magnification. For the normalized ratio of actual path to ideal path, an error was significantly higher at 10x magnification compared to those trajectories without magnification.

As shown in Figure 8, all the parameters showed a significant difference between the dominant hand setting and the non-dominant hand setting, except for normalized standard deviation of endpoint deviation. From all the significant parameters, the medians showed higher error using the non-dominant hand, except normalized mean path deviation shows higher in the dominant hand.

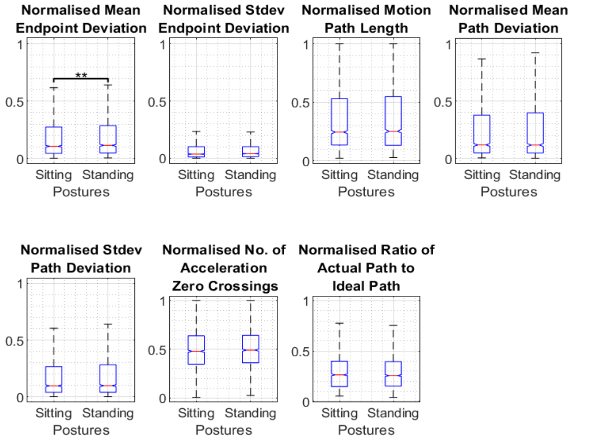

Fig. 6 Boxplots comparing both sitting and standing position for all the normalized parameters

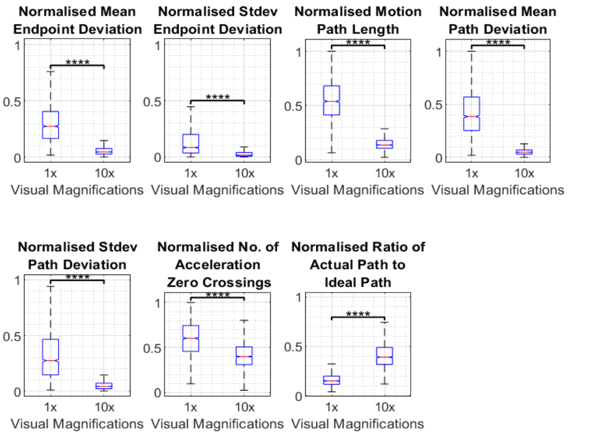

Fig. 7 Boxplots comparing both 1x and 10x visual magnifications for all the normalized parameters

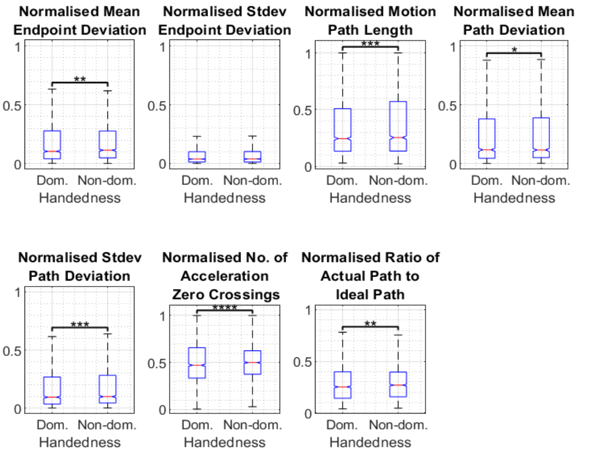

Fig. 8 Boxplots comparing both dominant hand and non-dominant hand groups for all the normalized parameters

TABLE I RESULT OF KS-TEST COMPARING NORMALIZED PARAMETERS FOR BOTH BODY POSTURES (SITTING AND STANDING POSITION).

Postures	Sitting	Standing	p-values
Normalized Parameters	Median, x̃		
Mean endpoint deviation	0.107	0.115	**0.008****
Stdev endpoint deviation	0.036	0.039	0.096
Motion path length	0.245	0.253	0.320
Mean motion path deviation	0.117	0.116	0.320
Stdev motion path deviation	0.095	0.097	0.743
No of Zero Crossings	0.479	0.491	0.131
Ratio of Actual Path to ideal path	0.263	0.256	0.340

TABLE II RESULT OF KS-TEST COMPARING NORMALISED PARAMETERS FOR BOTH 1X AND 10X MAGNIFICATION.

Visual Magnification	1x	10x	p-values
Normalized Parameters	Median, x̃		
Motion path length	0.537	0.136	<0.001***
Mean endpoint deviation	0.275	0.047	<0.001***
Stdev endpoint deviation	0.084	0.016	<0.001***
Mean motion path deviation	0.385	0.048	<0.001***
Stdev motion path deviation	0.273	0.041	<0.001***
No of Zero Crossings	0.602	0.398	<0.001***
Ratio of Actual Path to ideal path	0.149	0.389	<0.001***

TABLE III RESULT OF NORMALIZED PARAMETERS FOR BOTH DOMINANT AND NON-DOMINANT HAND WITH KS TEST P-VALUES.

Handedness	Dom hand	Non-dom hand	p-values
Normalized Parameters	Median, x̃		
Mean endpoint deviation	0.105	0.115	**0.002****
Stdev endpoint deviation	0.037	0.038	0.712
Motion path length	0.244	0.253	**<0.001*****
Mean motion path deviation	0.117	0.116	**0.017***
Stdev motion path deviation	0.093	0.098	**0.001****
No of Zero Crossings	0.471	0.499	**<0.001*****
Ratio of Actual Path to ideal path	0.251	0.268	**0.003****

VI. DISCUSSION

The current study showed that the standing and sitting positions are not affected surgical performance as there was no significant difference found in terms of endpoint precision, motion path length, motion path accuracy, motion path precision, motion smoothness, and economy of movement. Interestingly, endpoint accuracy showed a significant difference between sitting and standing positions. Although subjects were uncomfortable while performing the task, the dexterity performance was not affected by different postures of standing and sitting. This is similar to the findings by Ramakrishnan [21]. However, the subjects performed less accurately when in a standing position compared to a sitting position during static motion. Hence, a sitting position is recommended while performing surgical procedures that required higher accuracy, such as microsurgery [29].

Visual magnification could affect performance. With the aid of 10x magnification, the subjects were able to manipulate the cursor for both static and dynamic motion more accurately and precisely. Results showed the endpoint accuracy, endpoint precision, motion path accuracy, and motion path precision were higher while using 10x magnifications. Although longer motion path length was performed without magnification, the economy of movement shows better, as the motion was not easy to be manipulated when the motion was visually magnified to 10x. However, the motion shows less smoothness while performing the assessment as it is affected by the longer path length performed. The longer the path length on the motion, the lesser the smoothness performed that found in this study.

The current study also showed differences in endpoint accuracy, motion path accuracy, motion path precision, motion path length, motion smoothness, and economy of movement between dominant hand and non-dominant hand. Only endpoint precision showed no significant differences between the two hands. Performing surgical tasks using a non-dominant hand has similar static precision while using the dominant hand. Thus, ambidexterity can be observed in the parameter of endpoint precision only in this study. Yet, different specialties would have different requirements regarding ambidexterity skills. For instance, laparoscopic surgery required higher ambidexterity skills while performing some crucial surgical procedures [30].

Surprisingly, the median for average motion path deviation was found higher using the dominant hand compared to the non-dominant hand while performing the assessment task. Although it shows higher in the median for using the dominant hand, its distribution shows significantly lower compared to using the non-dominant hand.

VII. CONCLUSIONS

In summary, the study had identified that standing position affects the endpoint accuracy. The result of this investigation shows that different body postures will not affect the manual dexterity performance throughout the experiments. One of the more significant findings to emerge from this study is that different visual magnifications would affect the dexterity while performing the surgical task. The study also confirmed the findings of Su et al., which found that using 10x visual magnification shows better accuracy in both static and dynamic motions [27]. In addition, motion precision and motion smoothness show better while using 10x magnification in this study, yet the economy of movement shows inferior as the manipulations are not easy to control when the motion was visually magnified to 10x. Besides that, the ambidexterity skills had identified on the parameters of endpoint precision in this study. This research extends our understanding of different physical factors that might affect surgical performance, especially for visual magnifications. A limitation of this study is that the subjects from the different surgical backgrounds were being grouped together. Hence, more research on different specialties and different years of experience are needed to be investigated as different specialties might have different performance on different factors.

ACKNOWLEDGMENT

The authors would like to thank the Ministry of Health Malaysia (MOH) for ethical approval in this study. This study was supported by the Ministry of Education Malaysia (MOE) and Universiti Teknologi Malaysia (UTM) under the Fundamental Research Grant Scheme (FRGS) R.J130000.7823.4F900. The authors would like to thank all the subjects for their participation in this study. Ying Kit received a Zamalah scholarship from Universiti Teknologi Malaysia.

REFERENCES

[1] C. Villanueva, M. Doyle, J. Berger, G. Fermanis, and D. Glenn., Surgical Removal of an Unusual Massive Mediastinal Tumour Preceded by Interventional Embolisation, Hear. Lung Circ., 26 (2) (2017) e7–e10. doi: 10.1016/j.hlc.2016.07.013.

[2] R. K. Khouri et al., Tissue-engineered breast reconstruction with brava-assisted fat grafting: A 7-year, 488-patient, multicenter experience, Plast. Reconstr. Surg., 135(3) (2015) 643–658. doi: 10.1097/PRS.0000000000001039.

[3] Z. Li et al., Acute Blockage of Notch Signaling by DAPT Induces Neuroprotection and Neurogenesis in the Neonatal Rat Brain After Stroke, Transl. Stroke Res., 7(2) (2016) 132–140. doi: 10.1007/s12975-015-0441-7.

[4] A. Joseph, S. Bayramzadeh, Z. Zamani, and B. Rostenberg., Safety, Performance, and Satisfaction Outcomes in the Operating Room: A Literature Review, Heal. Environ. Res. Des. J., 11(2) (2018) 137–150. doi: 10.1177/1937586717705107.

[5] L. A. Yurteri-Kaplan et al., Sitting versus standing makes a difference in musculoskeletal discomfort and postural load for surgeons performing vaginal surgery, Int. Urogynecol. J., 30(2) (2018) 231–237. doi: 10.1007/s00192-018-3619-1.

[6] M. L. Carlson, D. J. Archibald, A. J. Sorom, and E. J. Moore., Under the microscope: Assessing surgical aptitude of otolaryngology residency applicants, Laryngoscope, 120(6) (2009) 1109–1113. doi: 10.1002/lary.20914.

[7] N. F. Z. Hisham, A. A. Jamal, and W. M. R. W. Idris., Lower limb walking gait profiling using marker-less motion capture with GDL and R-GDL methods to assist physiotherapy treatment, SSRG Int. J. Eng. Trends Technol.,1 (2020) 44–51. doi: 10.14445/22315381/CATI2P207.

[8] L. Sbernini, L. R. Quitadamo, F. Riillo, N. D. Lorenzo, A. L. Gaspari, and G. Saggio., Sensory-Glove-Based Open Surgery Skill Evaluation, IEEE Trans. Human-Machine Syst., (2018) 1–6. doi: 10.1109/THMS.2017.2776603.

[9] J. Gong and J. Lach., Motion marker discovery from inertial body sensors for enhancing objective assessment of robotic surgical skills, 4th Int. Symp. Bioelectron. Bioinformatics, ISBB,(2015) 215–218. doi: 10.1109/ISBB.2015.7344962.

[10] T. J. Kirby., Dexterity testing and residents' surgical performance, Trans. Am. Ophthalmol. Soc., 77 (1979) 294–307.

[11] J. Peirs et al., Design of an Optical Force Sensor for Force Feedback during Minimally Invasive Robotic Surgery, Eurosensors XVII, (2003) 1063–1066. [Online].Available: http://people.mech.kuleuven.ac.be/~jpeirs/Papers/Paper_Eurosensors_2003_MIS_sensor_extended.pdf.

[12] S.-H. Mi, Z.-G. Hou, F. Yang, X.-L. Xie, and G.-B. Bian., A collision response algorithm for 3D virtual reality minimally invasive surgery simulator, 26th Chinese Control Decis. Conf. (2014 CCDC), (2014) 4594–4599. doi: 10.1109/CCDC.2014.6852993.

[13] V. Datta, S. Mackay, M. Mandalia, and A. Darzi., The use of

electromagnetic motion tracking analysis to objectively measure open surgical skill in the laboratory-based model, J. Am. Coll. Surg., 193(5) (2001) 479–485. doi: 10.1016/S1072-7515(01)01041-9.

[14] A. J. Hung, I. S. Jayaratna, K. Teruya, M. M. Desai, I. S. Gill, and A. C. Goh., Comparative assessment of three standardized robotic surgery training methods, BJU Int., 112(6) (2013) 864–871. doi: 10.1111/bju.12045.

[15] J. Bric, M. Connolly, A. Kastenmeier, M. Goldblatt, and J. C. Gould., Proficiency training on a virtual reality robotic surgical skills curriculum, Surg. Endosc., 28(12) (2014) 3343–3348. doi: 10.1007/s00464-014-3624-5.

[16] P. A. Kenney, M. F. Wszolek, J. J. Gould, J. A. Libertino, and A. Moinzadeh., Face, Content, and Construct Validity of dV-Trainer, a Novel Virtual Reality Simulator for Robotic Surgery, Urology, 73(6) (2009) 1288–1292. doi: 10.1016/j.urology.2008.12.044.

[17] V. Quan, B. Alaraimi, W. Elbakbak, A. Bouhelal, and B. Patel., Crossover study of the effect of coffee consumption on simulated laparoscopy skills, Int. J. Surg., 14 (2015) 90–95. doi: 10.1016/j.ijsu.2015.01.004.

[18] P. J. Bongers, P. D. Van Hove, L. P. S. Stassen, J. Dankelman, and H. W. R. Schreuder., A new virtual-reality training module for laparoscopic surgical skills and equipment handling: Can multitasking be trained? A randomized controlled trial, J. Surg. Educ., 72(2) (2015) 184–191.doi: 10.1016/j.jsurg.2014.09.004.

[19] J. Y. Lee, P. Mucksavage, D. C. Kerbl, V. B. Huynh, M. Etafy, and E. M. McDougall., a Validation study of a virtual reality robotic simulator role as an assessment tool? J. Urol., 187(3) (2012) 998–1002. doi: 10.1016/j.juro.2011.10.160.

[20] G. Islam, K. Kahol, B. Li, M. Smith, and V. L. Patel., Affordable, web-based surgical skill training and evaluation tool, J. Biomed. Inform., 59 (2016) 102–114. doi: 10.1016/j.jbi.2015.11.002.

[21] V. R. Ramakrishnan and B. M. Milam., Ergonomic analysis of the surgical position in functional endoscopic sinus surgery, Int. Forum Allergy Rhinol., 7(6) (2017) 570–575. doi: 10.1002/alr.21911.

[22] M. Eichenberger, N. Biner, M. Amato, A. Lussi, and P. Perrin., Effect of Magnification on the Precision of Tooth Preparation in Dentistry, Oper. Dent., 43(5) (2018) 501–507. doi: 10.2341/17-169-c.

[23] A. Skinner, G. Auner, M. Meadors, and M. Sebrechts., Ambidexterity in laparoscopic surgical skills training," Stud. Health Technol. Inform., 184 (2013) 412–416. doi: 10.3233/978-1-61499-209-7-412.

[24] F. H. F. Elneel, F. Carter, B. Tang, and A. Cuschieri., Extent of innate dexterity and ambidexterity across handedness and gender: Implications for training in laparoscopic surgery, Surg. Endosc. Other Interv. Tech., 22(1) (2008) 31–37. doi: 10.1007/s00464-007-9533-0.

[25] S. N. Z. Ahmmad, E. Su Lee Ming, Y. Che Fai, S. Sood, and A. Gandhi., Objective measurement for surgical skill evaluation, J. Teknol., 78 (2016) 7–5,145–152. doi: 10.11113/jt.v78.9461.

[26] S. N. Z. Ahmmad et al., Objective assessment of surgeon's psychomotor skill using virtual reality module, Indones. J. Electr. Eng. Comput. Sci., 14(3) (2019) 1533–1543. doi: 10.11591/ijeecs.v14.i3.pp1533-1543.

[27] E. L. M. Su, T. L. Win, W. T. Ang, T. C. Lim, C. L. Teo, and E. Burdet., Micromanipulation accuracy in pointing and tracing investigated with a contact-free measurement system, Proc. 31st Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. Eng. Futur. Biomed. EMBC, (2009) 3960–3963. doi: 10.1109/IEMBS.2009.5333665.

[28] F. S. Nahm., Nonparametric statistical tests for the continuous data: The basic concept and the practical use, Korean J. Anesthesiol., 69(1) (2016) 8–14. doi: 10.4097/kjae.2016.69.1.8.

[29] L. Mattos, D. Caldwell, G. Peretti, F. Mora, L. Guastini, and R. Cingolani., Microsurgery robots: addressing the needs of high-precision surgical interventions, Swiss Med. Wkly., 146 (2016). doi: 10.4414/smw.2016.14375.

[30] S. S. Srouji et al., Robotic Assistance Confers Ambidexterity to Laparoscopic Surgeons, J. Minim. Invasive Gynecol., 125(1) (2017) 76–83. doi: 10.1016/j.jmig.2017.07.010.