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Full paper

Force Variability as an Objective Measure of Surgical Skill

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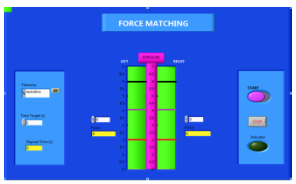
Graphical abstract



Abstract

This study investigated the force variability of subjects with different level of surgical skills for different force levels. Twelve participants were recruited from three different levels of surgical experiences: A group of surgeon (N = 4), medical student (N = 3) and engineering student (N = 5) underwent a simple finger force control task using a custom developed 'Force Matching' module. Three different levels of target force were used: 2 N, 4 N, and 6 N. The task was performed simultaneously using right and left hands. The mean error of force was measured to compare the performance between the three group using Kruskal-Wallis test. A statistically significant difference was detected among the three groups at 2 N when using right hand. We also found that the surgeon group made less error compared to the two other groups at force level 4 N and 6 N for both hands. This finding has important implication for developing a parametric assessment model to evaluate basic skill level in surgical procedures. However, for most accurate result, a big sample size of subject is required.

Keywords: Force matching; error of force; parametric assessment

Abstrak

Kajian ini menyiasat variasi daya subjek yang mempunyai tahap kemahiran pembedahan yang berlainan bagi tahap daya yang berbeza. Dua belas orang peserta telah direkrut dari tiga kumpulan yang berbeza tahap pengalaman pembedahan. Sekumpulan pakar bedah (N = 4), pelajar perubatan (N = 3) dan pelajar kejuruteraan (N = 5) telah menjalani ujian kawalan daya jari yang ringkas menggunakan module 'Padanan Daya'. Tiga tahap daya sasaran telah digunakan; 2 N, 4 N, 6 N. Ujian itu dilaksanakan secara serentak menggunakan tangan kanan dan kiri. Purata kesalahan daya telah dikenal pasti untuk membandingkan prestasi antara tiga kumpulan menggunakan ujian Kruskal-Wallis. Satu perbezaan ketara ditunjukkan antara tiga kumpulan adalah pada 2 N dengan menggunakan tangan kanan. Kami juga mendapati kumpulan pakar bedah telah membuat kurang kesalahan berbanding dengan kumpulan pelajar pada tahap daya 4 N dan 6 N. Penemuan ini membawa implikasi yang penting untuk membangunkan model penilaian parametrik untuk menilai tahap kemahiran asas dalam prosedur pembedahan. Walau bagaimanapun, untuk mendapatkan hasil yang tepat, sampel saiz yang besar diperlukan.

Kata kunci: Padanan daya; kesalahan daya; penilaian parametrik

■1.0 INTRODUCTION

For a surgical procedure to complete successfully, it requires 75% of decision making and 25% of technical dexterity [1]. In 2001, Cuschieri *et al*. conducted opinion survey among a group of master surgeons on selection of surgical trainee and they found innate dexterity of the individual as the strongest factor to determine the level of technical skill [2]. Besides innate dexterity, mastering a technical skill in surgical procedure requires multiple stages of training and a great amount of hands-on experience. The trainee must accumulate and go through different experimental and clinical conditions to be competent.

More than a century ago, teaching of dexterous skills relied heavily on apperentice-style training [3]. In current training practices, the expert will demonstrate the right techniques and trainees will take time to practise, often independently. The expert will then assess the performance of trainees using direct observation. It is very difficult to judge the performances of trainees in term of their psychomotor skill and to measure critical elements of skill attainment using direct observation. Furthermore, direct observation is subjective assessment, leading to recall bias [4] and affected by inter and intra-rater variability. Over the recent years, there has been an explosive growth of interest in replacing traditional subjective assessment techniques with more objective methods [5, 6]. Many researchers believe that finding a reliable method of measuring surgical skills in objective way is now an urgent matter [7, 8].

Several motion analysis and force measurement systems have been developed to measure hand performance of surgeon at different levels [9, 10]. There are several measurement parameters that have been studied previously, such as economy of movement, motion smoothness, force, time and path error [11, 12, 13]. These parameters are proposed to be used for surgical skill assessment [14].

For this study, we propose the measurement of force variability to be used as an assessment parameter for technical competency. Surgeons usually need to apply different force levels and maintain the force level when handling variety of tools during different types of procedures. Very often when performing a procedure, the surgeon needs to grip efficiently without damaging the patient's tissue. Increased force on the tissue could result in tissue damage and lead to muscle fatigue. The ability to apply and control the force in an appropriate way and safe handling are very important especially during training. In this study, we compare the ability of experienced surgeons in controlling their force level against medical students and subjects with no medical training. Three level of forces: 2 N, 4 N and 6 N were used as target forces.

2.0 EXPERIMENTAL

An experimental module was developed to investigate subject's force variability at different target force. Twelve subjects completed the study and they were divided into three groups: surgeon, medical student and engineering student. The subjects comprised 4 surgeons with at least 3 years experience in surgery, 3 medical students and 5 engineering students. All the subjects were right-handed. Two force sensors (FSG15N1A, Honewell Inc., USA) were used in this module to measure the force during the experiment. These sensors are able to measure forces up to 15 N.

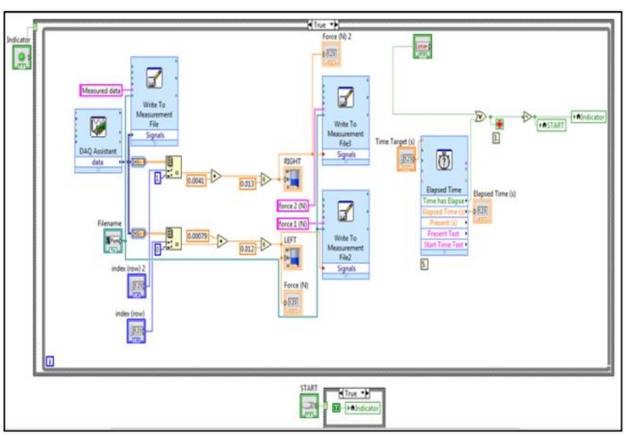


Figure 1 Block diagram

Laboratory Virtual Instrument Engineering Workbench or also known as LabVIEW software was used to design a graphical user interface (GUI) to let the subject monitor the amount of the force exerted. LabVIEW consists of two major features, which are the Block Diagram (Figure 1) and the Front Panel (Figure 2). The NI-USB 6009 data acquisition card was used to link the input force from the subject to the LabVIEW interface. It consists of 8 different analog voltage inputs and 12 channels for digital input or output (digital I/O lines).

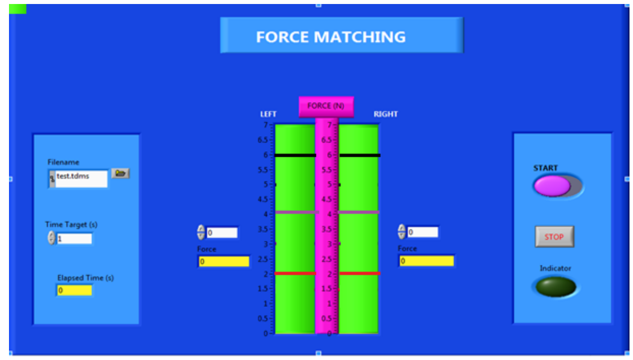


Figure 2 Front panel view

In this experiment, each subject underwent the finger force control task using force matching module. The task was performed simultaneously using right and left hand. During the experiment, subjects were asked to sit on an adjustable chair facing the display screen on the table and held the force sensor between their index finger and thumb, with one sensor in each hand, as shown in Figure 3.

Figure 3 Force Matching experiment

On the screen, the GUI LABVIEW was used as a visual feedback. The GUI displayed three target forces that the subject needs to aim for. The measured data, which was the amount of force exerted by the subject, was also displayed. The subject was instructed to generate the right amount of force so that it matched the target force as accurately as possible by pressing the force sensor with their fingers. The target force was set at 2 N, 4 N and 6 N and each target force was indicated as different lines (Figure 3). When the exerted force reached the targeted level, they need to maintain it for 20 seconds until the program stopped. Each subject practiced one trial set for a few seconds to ensure that they understood and were familiar with the task. To start the experiment, button '**START**' was pressed by the experimenter once the subject was ready. All data were recorded at 1000 Hz for each trial. Subjects performed three trials for each level of target forces. The total experiment time for each subject was less than 30 minutes.

3.0 DATA ANALYSIS

Data pre-processing and statistical analysis were computed using Matlab software (The Mathworks, USA) and SPSS statistic software (Statistical Package for the Social Sciences).

Figure 4 shows the output of force signal versus the time when the level of target force was 2 N. The mean error was measured by calculating the difference of measured force from the targetted force. Data obtained from the force sensors was extracted only at 5 s after the experiment begun until 15 s. This was to ensure that every measured force from all subjects was taken at steady state level when the subject was maintaining the force.

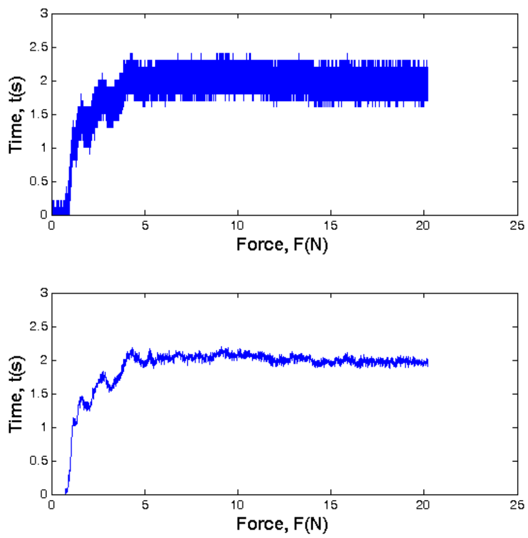


Figure 4 Output signal; before filter (top) and after filter (bottom)

Prior to analysis, the data was filtered using Butterworth low pass filter at 50 Hz to ensure high frequency noise was removed. Normality distribution of data subset was tested using Sharpiro-Wilk statistical test. The result showed that the data was not normally distributed therefore, non-parametric tests would be used for all analyses. The Kruskal-Wallis test was used to compare the differences among the three study groups. This test evaluates the differences among the groups by estimating differences in median and mean ranks among them. If there is a statistically significant result, a follow- up method with post-hoc test using Mann-Whitney U was applied to determine which are the differences between two groups. A probability of $p < 0.05$ was considered to be statistically significant.

4.0 RESULTS AND DISCUSSION

The result in this study will focus on the mean error in force level among three groups, which are surgeons, medical students and engineering students. Figure 5 and Figure 6 show the mean of force error performed by three groups using their left hand and right hand. Data was evaluated using Kruskal-Wallis non-parametric test to evaluate the mean error differences among the three groups. We identified that there is no statistically significant difference of the error across the three groups for all level of forces test using left hand. At 2 N, χ^2 (2, n= 36) = 2.329, p = 0.312; at 4 N, χ^2 (2, n= 36) = 1.163, p = 0.559; at 6 N, χ^2 (2, n= 36) = 1.797, p = 0.407.

Meanwhile for the right hand test, Kruskal-Wallis test revealed a statistically significant difference in the mean of force error at 2 N across three different groups χ^2 (2, n= 36) = 7.576, p = 0.023. Subset analysis (Mann-Whitney U test) were performed and results showed a significant difference between surgeon versus engineering student group, p = 0.023 and medical student versus engineering student, p = 0.03. However, no significant difference was detected between surgeon and medical student groups, p = 0.434. The result of Kruskal-Wallis test at 4 N and 6 N showed no statistically significant differences between the three groups although the surgeon group had lower mean error overall. At 4 N, χ^2 (2, n= 36) = 0.695 p = 0.706; at 6 N, χ^2 (2, n= 36) = 3.359, p = 0.186.

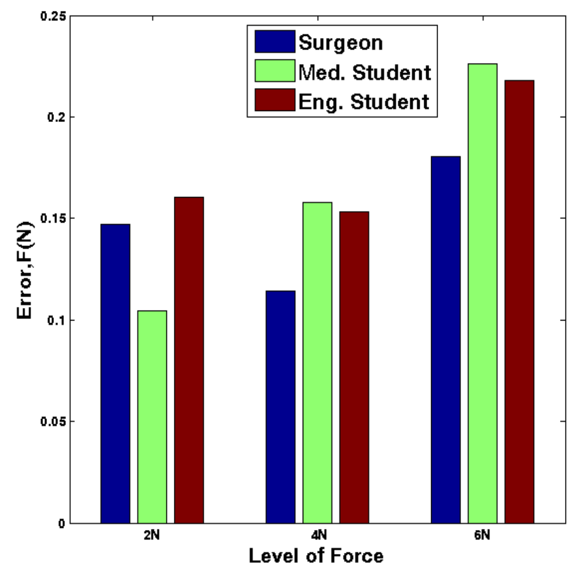


Figure 5 Mean of error (left hand)

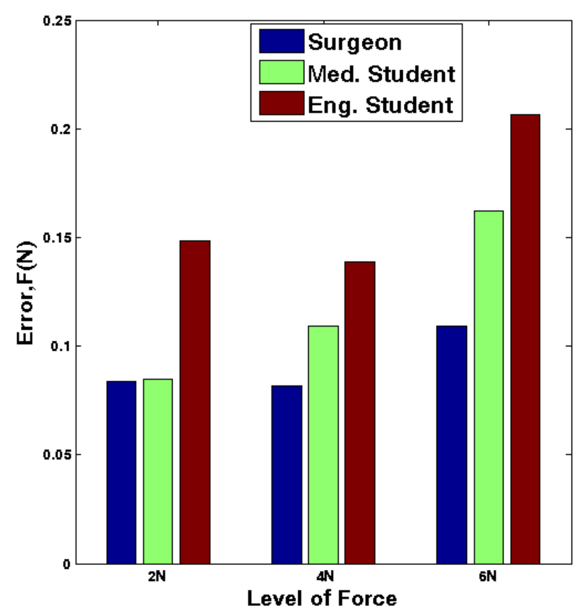


Figure 6 Mean of error (right hand)

The summary of the results from Kruskal-wallis test are presented at Table 1 and Table 2. With these, the median and mean rank values of the data was shown. This result showed which group had the highest overall ranking that corresponds to the highest mean in force error. From the result, we observed that at 2 N, medical student made the least error compared to surgeon and engineering students. However, at 4 N and 6 N, surgeon showed the least error compared to the two other student groups. Mean error for right and left hands increased as force level increased, indicating that the more strength required, the more error would be produced. Thus, surgical tools should be designed to be as light-weight as possible to avoid over-exertion by the surgeons. The over-exertion of muscle tend to lead to larger error and the inability to control force level may result in greater tissue damage. Excessive force may also lead to higher positional errors during surgical procedure.

This study also found that the error from the right hand was smaller compare to the left hand. In other words, by using the right hand (dominant) when controlling the force, it was more stable and precise to the target compared to the left hand (non-dominant). Despite being an extremely simple pressing task, the superiority of the dominant hand is prominent indicating that technical dexterity can be identified via this simple task. The right hand, being more stable and more in use, is assumed to be of higher dexterity and showed lower error in this task. For tasks requiring high precision and accuracy, it is important to plan that it will be executed using the dominant hand as much as possible. Appropriate handling and control the finer force is essential to minimize the error during the surgical procedure.

Table 1 Control finger force error for left hand

Group		Level of Force		
		2 N	**4 N**	**6 N**
Surgeon	Mean rank	18.58	15.83	16.42
	Median	0.1317	0.1122	0.1065
Medical student	Mean rank	14.22	20.11	22.44
	Median	0.0725	0.1212	0.2095
Engineering Student	Mean rank	21.00	19.67	17.80
	Median	0.1528	0.1378	0.1586
Kruskal- Wallis test		*p*=0.312	*p*=0.559	*p*=0.407

Table 2 control finger force error for right hand

Group		Level of Force		
		2 N	**4 N**	**6 N**
Surgeon	Mean rank	15.42	16.58	14.17
	Median	0.0793	0.0554	0.1005
Medical student	Mean rank	13.22	20.33	19.11
	Median	0.0584	0.1369	0.1305
Engineering Student	Mean rank	24.13	18.93	21.60
	Median	0.1435	0.1252	0.1664
Kruskal- Wallis test		*p*=0.023	p=0.706	*p*=0.186

5.0 CONCLUSION

The Force Matching module was developed to identify the force control of subjects using a simple pinching task. This pinching movement is normally used when grasping small objects or tools during a surgical procedure. Results showed that measurement of force variability could be used to differentiate between performance of the medical group and the non-medical group. The expert surgeon and medical student groups recorded less error compared to the engineering student group when using their dominant hand at 2 N and this difference was statistically significant. In general, the surgeons recorded a lower mean error compared to the other groups at 4 N and 6 N using both hands although the difference in mean was not statistically significant. Further analysis with bigger subject population will be conducted to validate the experimental data. If the task parameter can clearly differentiate between surgeon and non-surgeon group, this can be used as one objective measure to assess baseline skill level.

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References

[1] F. Spencer. 1978. Teaching and Measuring Surgical Technique-The Technical Evaluation of Competence. *Bulletin of the American College of Surgeons*. 63: 9–12.

[2] A. Cuschieri, N. Francis, J. Crosby and G. B. Hanna. 2001. What Do Master Surgeons Think of Surgical Competence and Revalidation? *American Journal of Surgery*. 182(2): 110–6.

[3] B. N. Carter. 1952. The Fruition of Halsted's Concept of Surgical Training. *Surgery*. 32: 518–527.

[4] S. N. Z. Ahmmad, E. L. M. Su, C. F. Yeong and F. K. C. Harun. 2011. Assessment Methods for Surgical Skills. *World Academy of Science, Engineering and Technology Conference*. 752–758.

[5] S. L. Cremers, J. B. Ciolino, Z. K. Ferrufino-Ponce and B. A. Henderson. 2005. Objective Assessment of Skills in Intraocular Surgery (OASIS). *Ophthalmology*. 112(7): 1236–1241

[6] J. A. Martin, G. Regehr, R. Reznick, H. MacRae, J. Murnaghan, C. Hutchison and M. Brown. 1997. Objective Structured Assessment of Technical Skill (OSATS) for Surgical Residents. *British Journal of Surgery*. 84(2): 273–278.

[7] K. Moorthy, Y. Munz, S. K. Sarker and A. Darzi. 2003. Objective Assessment of Technical Skills in Surgery. *British Medical Journal*. 327(7422): 1032–1037.

[8] A. Darzi, S. Smith and N. Taffinder. 1999. Assessing Operative Skill: Needs To Become More Objective. *British Medical Journal*. 318(7188): 887–888.

[9] A. Dosis, R. Aggarwal, F. Bello, K. Moorthy, Y. Munz, D. Gillies and A. Darzi. 2005. Synchronized Video and Motion Analysis for The Assessment of Procedures in The Operating Theater. *Archives of Surgery*. 140(3): 293–299.

[10] D. Vivek, S. Mackay, M. Mandalia and A. Darzi. 2001. The Use of Electromagnetic Motion Tracking Analysis To Objectively Measure Open Surgical Skill in The Laboratory-Based Model. *Journal of the American College of Surgeons*. 193(5): 479–485.

[11] T. F. Then, E. L. Su, S. N. Z. Ahmmad and C. F. Yeong. 2013. Massed Training Versus Interval Training for Computer-Based Suturing Skill Acquisition. *Journal of Medical Imaging and Health Informatics*. 3(4): 503–508.

[12] E. L. Su, G. Ganesh, C. F. Yeong, C. L. Teo, W. T. Ang and E. Burdet. 2011. Effect of Grip Force and Training in Unstable Dynamics on Micromanipulation Accuracy. *IEEE Transaction on Haptics: Special Issue on Haptics in Medicine and Clinical Skill Acquisition*. 4: 167–174.

[13] S. N. Z. Ahmmad, E. L. Su and C. F. Yeong. 2013. Effect of Intermittent Haptic Disturbance in Motor Skill Training. *Applied Mechanics and Material*. 432: 403–408.

[14] S. N. Z. Ahmmad, E. L. Su, C. F. Yeong and A. L. T. Narayanan. 2014. Experimental Study of Surgeon's Psychomotor Skill Using Sensor-Based Measurement. *Procedia Computer Science*. 42: 130–137.