31st Annual International Conference of the IEEE EMBS
Minneapolis, Minnesota, USA, September 2-6, 2009

Influence of Visual Feedback and Speed on Micromanipulation Accuracy

E. S. Ananda, W.T. Latt, C.Y. Shee, Eileen L.M. Su, E. Burdet, T.C. Lim, C.L. Teo, W.T. Ang, *Member*, *IEEE*

***Abstracts*—Accuracy in micromanipulation tasks is limited and it is important to identify various factors affecting it. This paper studies the effect of visual magnification, speed and handedness to micromanipulation accuracy using microscope and LCD screen for feedback. Magnification of visual feedback increases the accuracy, but large magnification does not provide further improvement beyond 16x. Further, we observed a trade off between speed and accuracy in tracing a circular path, i.e. faster speed reduces the speed control ability of the hand. Finally, dominant/non-dominant hand is found to affect accuracy in motion.**

I. Introduction

Limitations on human accuracy have imposed restrictions in microsurgery applications, such as in eye, hand and neurosurgery [1]. These limitations are primarily due to small involuntary movements that are inherent in hand motion, one of which is known as physiological tremor. In order to solve such problem, it is necessary to assess and understand several underlying factors that affect it.

Some works have studied the effect of beta-blockers [2], alcohol consumptions [3], caffeine in-take [4], and smoking habits [5] on hand tremor. Furthermore, findings in [6] demonstrate that microsurgical hand tremor increases following exercise.

There have also been studies in cognitive science related to eye and hand coordination in manipulation task. While doing certain task such as tracing, the subject depends on external cues such as visual feedback from the eyes which are used to monitor the instrument tip position in relation to the traced line [7]. It is expected that a better visual feedback leads to an increase in hand accuracy.

To our knowledge, the relationship between speed and accuracy in micromanipulation has not been studied. It is expected that the higher the speed, the lesser the accuracy, a phenomenon popularly known as speed-accuracy tradeoff in reaching and manipulation tasks. Hence, it will be insightful to study how visual feedback and speed affect the accuracy or performance in micromanipulation, where the movement is more refined and the error becomes relatively larger.

In this study, a surgical microscope was used to provide visual feedback with different levels of magnification. Alternatively, two-dimensional visual feedback with configurable magnification level was also provided by Graphical User Interface (GUI) shown on LCD monitor.

The authors: E.S., Ananda, W.T. Latt, C.Y. Shee, and W.T. Ang are with Nanyang Technological University, School of Mechanical and Aerospace Engineering. Contact: ANAN0021@ntu.edu.sg.

C.L. Teo is with National University of Singapore, School of Mechanical Engineering. E. Burdet and Eileen L.M. Su are with Imperial College London, Dept of Bioengineering. Dr. T.C. Lim is with National University Hospital, Singapore.

II. Methodology

A. Participants

Eighteen healthy subjects (16 males, 2 females) have given their consent to participate in the study. They were divided into three sample groups: 8 non-medically trained subjects, 4 general practitioners, and 6 junior surgeons who were attending micro-surgical course.

The subjects would be assessed based on three dexterity primitives that sufficiently represented kinematics of hand motion, i.e. *i*) pointing task, *ii*) tracing task, and *iii*) tracking task, following a moving target. The motion was clockwise for both tracing and tracking tasks.

B. Optical Sensing System

A two degree-of-freedom (DOF) contact-free micro motion sensing system was developed to assess hand micromanipulation performance [1]. The system consists of a PSD module (DL100-7PCBA3), a red laser diode (UT5-3.5G-650; 650nm, 3.5mW), Leica M651 table-top surgical operating microscope, a set of PC with LCD monitor, and data acquisition (DAQ) card (PD2-MF-150) slotted inside the PC motherboard to capture voltage outputs from PSD.

Tracing paper was pasted on the surface of the PSD. Eight markers of 0.4 mm diameter were printed on the tracing paper to provide 2 mm radius circular path for tracing task. The use of transparency was discouraged to prevent multiple laser spots due to internal reflection introduced on its surface that would therefore distort the visual feedback.

The system was properly fixed on the centre of mechanically isolated table and connected to a PC. National Instruments'LabVIEW 7.1 was used to create Graphical User Interface (GUI) that was meant for subjects to look on the LCD monitor during the experiment. In addition, it was used to perform data logging of voltage data through DAQ card.

The system resolution with the tracing paper was measured by computing RMS noise of a stationary spot (provided by the red laser diode) and found to be 0.8 μm. The accuracy was also observed by moving the laser diode attached to high precision motorized stages for 1 mm interval in each *x* and *y*-axis and found to be above 98% rms.

C. Experiment procedures

The experiment setup was realized to resemble actual surgical training courses. Each subject sat down in front of the table, had to rest his wrist and hold the red laser diode as comfortable as possible, pointing downwards. The subject would then be instructed on the specified tasks as shown on Table I.

The tasks basically consisted of three accuracy primitives mentioned earlier and performed in two different views, i.e. *screen* view (looking to GUI on LCD) and *microscopic* view (using surgical microscope) as shown in Fig. 1. Certain tasks would also involve the non-dominant hand.

Once the subject was ready, the data recording would start; each task was recorded once for 30 seconds. Subjects were allowed to take two minutes rest to avoid muscle fatigue that might be detrimental to the performance.

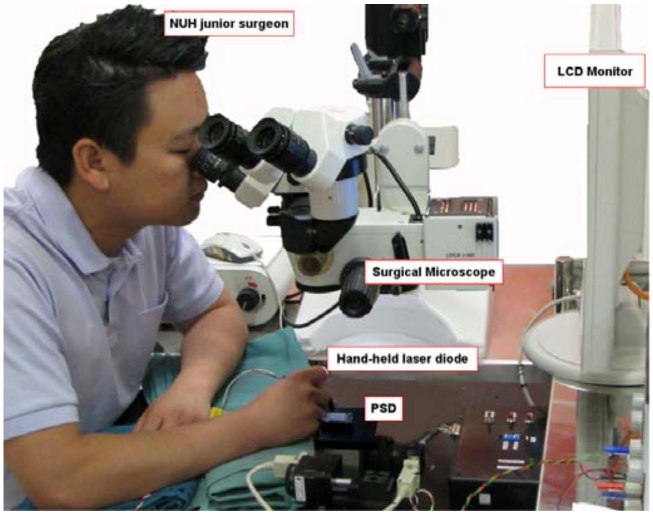

Fig. 1. Experiment setup with microscope and LCD monitor.

Moreover, three different speed constraints were used for tracing tasks, i.e. *slow* (0.25 – 0.75 mm/sec), *medium* (0.76 – 1.50 mm/sec), *fast* (1.51 – 2.20 mm/sec). Subjects would be notified by audio feedback if they moved beyond the specified speed. For example: the PC would play "Slower" WAV file if the task performed was too fast and vice versa.

TABLE I
LIST OF TASKS USED FOR THE EXPERIMENT

Visual feedback	Experiment steps
LCD screen	Tracing a circle for 1x, 16x, and 25x., medium speed
LCD screen	Tracking a circular trajectory for 1x, 16, and 25x, medium speed
LCD screen	Tracing a circle at preferred magnification in slow, medium, and fast speed
Microscope	Pointing task for 1x, 16x, and 25x
Microscope	Pointing task with non-dominant hand for 1x, 16x, 25x
Microscope	Tracing a circle for 1x, 16x, 25x, at medium speed
Microscope	Tracing a circle with non-dominant hand for 1x, 16x, and 25x, medium speed
Microscope	Tracing a circle at preferred magnification at slow, medium, and fast speed
Microscope	Tracing a square at preferred magnification at slow, medium, and fast speed

D. Collecting Raw-data

The voltage-outputs from the PSD were captured using DAQ card at sampling rate 166.67 Hz per channel. The actual position of the laser spot in x and y axes could be obtained using the method discussed in [1].

The recorded data would therefore contain x_i and y_i, displacement information. Offsets were found to be due to the variation in hand tilting position and were computed offline by taking the average values of full periods in x and y component. Data was then shifted accordingly (Fig. 3).

In order to obtain accuracy of a particular task, root-mean-square error (RMSE, in mm) was computed. The error of each instantaneous position was calculated based on the deviation from the ground truth. The ground truth values for pointing and circular tracing/tracking are the first position recorded and the 2 mm circular radius respectively.

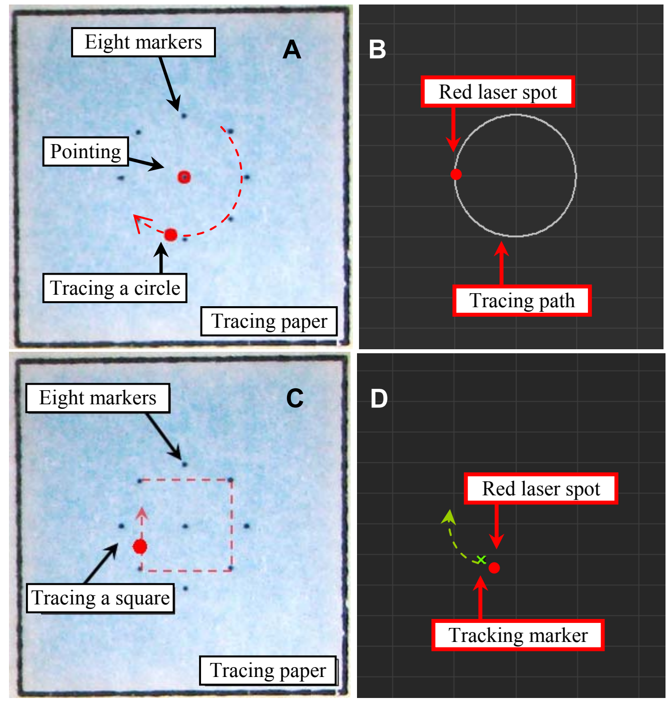

Fig. 2. Tasks performed under microscopic view (A, C) and on LCD screen (B, D). Three different accuracy primitives were used: pointing, tracing certain path, and tracking.

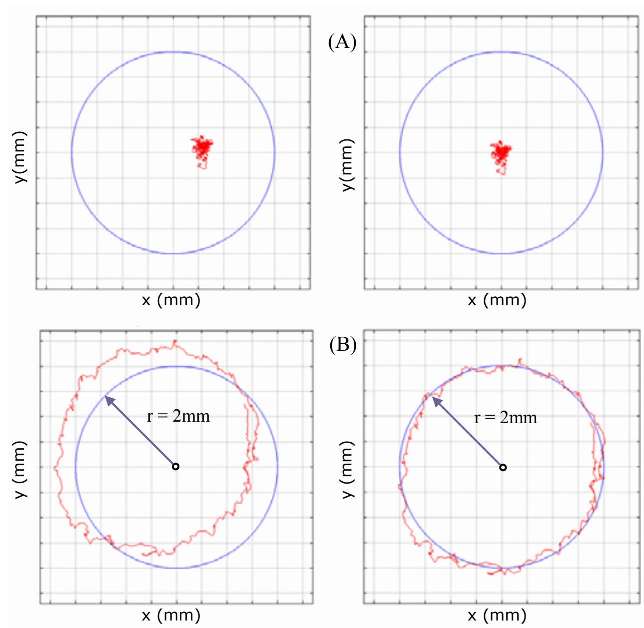

Fig. 3. Path before and after offset removal for: (A) pointing at 16x using left hand; and (B) tracing a circle at slow speed.

The displacement originated from both voluntary motion (non-tremulous) and error caused by physiological tremor.

To obtain the displacement caused by the voluntary motion only, x and y data were filtered by 2^{nd} order Butterworth point-to-point low pass filter in LabVIEW with 0.1 Hz cutoff frequency. After filtering, the speed v_i was computed by:

$$v_i = \frac{\text{displacement}}{\text{time}} = \frac{\sqrt{(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2}}{t_{\text{ch}}} \quad (1)$$

where i is the i-th sample of the filtered position, t_{ch} is interval timing between two samples per channel = $^1/_{166.67\ \text{Hz}}$.

Average value and standard deviation of every instantaneous speed v_i of a particular task were computed. Thus, the speed profile of each task a subject has performed can be known and used for subsequent analyses.

Student t-test was performed to the data using significance level of 0.01. The mean RMSE and standard error of mean of all subjects would also be plotted.

III. Results

A. Effect of magnification using screen view

There is significant decrease of RMSE in tracing a circular path in clockwise direction, between magnification 1x and 16x ($p < 0.001$ for normal subjects, $p < 0.005$ for general practitioners, and $p < 0.001$ for junior surgeons). There is no significant improvement between 16x and 25x ($p > 0.5$) for all sample groups (Fig. 4*a*).

There is significant decrease of RMSE in tracking between magnification 1x and 16x ($p < 0.007$ for all groups), but there is no significant improvement between 16x and 25x ($p > 0.5$ for normal subjects, $p > 0.5$ for general practitioners, and $p > 0.08$ for junior surgeons).

B. Effect of speed in tracing using screen view

As the hand moves from slow to fast speed, the overall RMSE increases (Fig. 4*b*). The increment is more significant from medium to fast speed ($p < 0.01$) than from slow to medium ($p > 0.35$ for normal subjects, $p > 0.84$ for general practitioners, and $p > 0.03$ for junior surgeons).

In fast movement, the standard deviation of the speed is higher than that for slow and medium speed (Fig. 5).

C. Effect of magnification in pointing (stationary) task under the microscope

There is decreasing trend of RMSE in pointing task among three magnification levels 1x, 16x, and 25x (Fig. 6*a*). For the dominant hand, the accuracy difference between 1x and 16x ($p < 0.006$) is apparent but not between 16x and 25x ($p > 0.74$). Similarly, with the non-dominant hand, a considerable difference in accuracy between 1x and 16x ($p < 0.008$) is observed, but not between 16x and 25x ($p > 0.11$).

Comparisons between dominant and non-dominant hand in pointing task indicate that there is no significant difference in accuracy (for each magnification: $p > 0.65$).

D. Effect of magnification in tracing a circular path under the microscope

Tracing in using the dominant hand shows a considerable decrease in RMSE between magnification 1x and 16x ($p < 0.001$ for all groups), but not for magnification between 16x and 25x ($p > 0.37$ for normal subjects, $p > 0.56$ for general practitioners, and $p > 0.65$ for junior surgeons).

Similar trend applies for the non-dominant hand (Fig. 6*b*). RMSE decreases insignificantly for magnification between 16x and 25x ($p > 0.20$ for normal subjects, $p > 0.33$ for general practitioners, and $p > 0.17$ for junior surgeons).

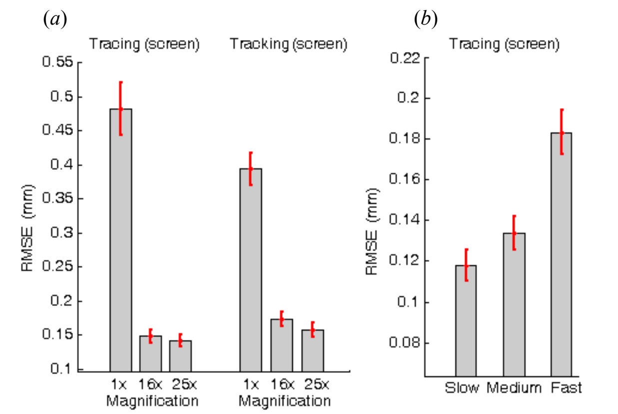

Fig. 4. (*a*) Effect of magnification and (*b*) speed on tracing and tracking on screen view with the dominant hand using screen view.

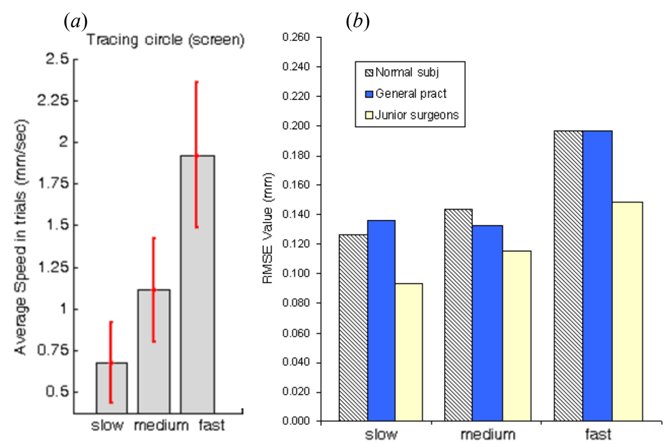

Fig. 5. (*a*) Average speed for tracing on screen view; and (*b*) accuracy based on different sample group

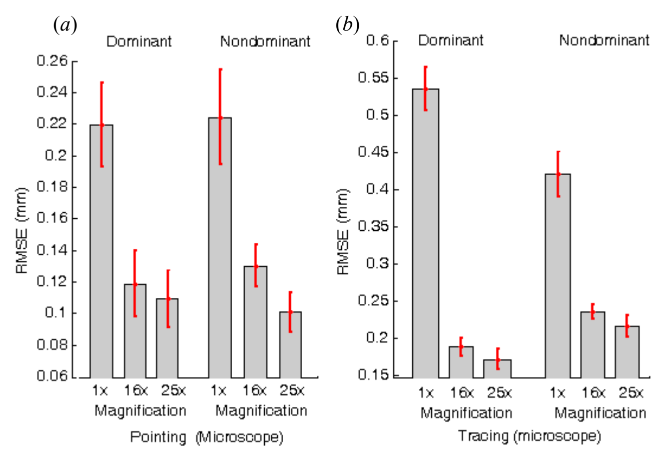

Fig. 6. (*a*) Effect of magnification on pointing task accuracy and (*b*) on tracing circular path at medium speed with dominant and non-dominant hand under the microscope.

The accuracy difference between dominant and non-dominant hand in doing tracing circular path is significant (for each magnification: $p = 0.009, 0.005, 0.02$).

E. Effect of speed on tracing under the microscope

Tracing with speed variation under preferred magnification in clockwise direction involves a circular and square path (Fig. 7*a*). As the speed changes from slow to fast in tracing a circular path, there is an increasing trend in RMSE though it is not that significant ($p > 0.05$ for all groups). For square path, however, a reduction of RMSE was observed and was not significant ($p > 0.05$ for all groups).

For both circular and square paths, the standard error of the speed gets higher when the subjects performed the task at faster speed (Fig. 7*b*).

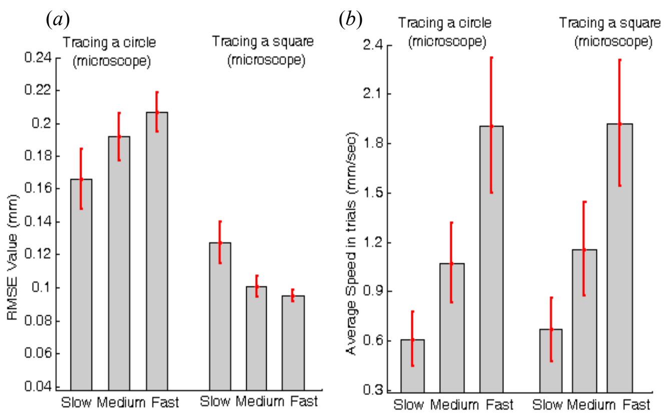

Fig. 7. (*a*) Effect of speed on tracing accuracy (both circle and square paths, clockwise) under the microscope using dominant hand; and (*b*) corresponding speed profile.

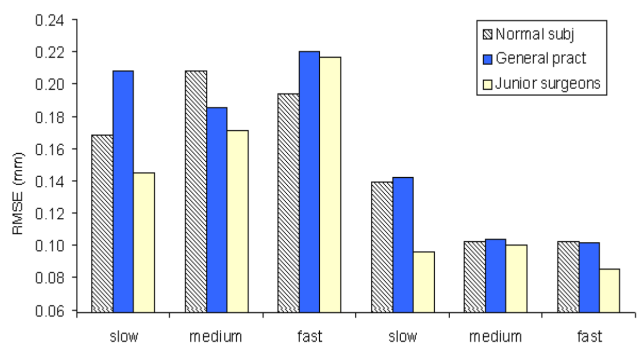

Fig. 8. Accuracy of different sample groups in tracing tasks

IV. Discussion

In both screen and microscopic views, larger magnification contributes to improvement in micromanipulation accuracy. However, high magnification (larger than 16x in our setup) does not bring significant improvement to the accuracy. This is in agreement with [8] where no further improvement in accuracy was found beyond 10x.

The accuracy during pointing task can represent the static performance in micromanipulation. No significant difference is observed in accuracy between the dominant and non-dominant hand. In tracing task, however, the hand is no longer static and moves to follow certain pattern. Here, there is more apparent difference in accuracy between the two hands. Dominant hand seems to perform better and thus it may explain why it is preferred for people to use dominant hand in their works.

In tracing a circular path for both screen and microscopic view (Fig. 4*b* and Fig. 7*a*), the accuracy drops as the speed of movement increases. Hence, there is a trade-off between speed and accuracy of the task. This trade-off, however, does not appear in tracing a square path. Further, the accuracy in tracing a circular path is lower than that in square shape. This may be due to the fact that it is easier in terms of eye-hand coordination to perform a task in one direction (either in x or y-direction), and tracing a circle involves a change the direction. This result agrees with earlier finding in [9].

It is necessary to conduct further experiment on the square path to get deeper understanding on the speed-accuracy tradeoff. Instead of only four corner-markers, more dot-markers will be used to create a square path. The experiment will also include performing the task on screen view so that the trend for both screen and microscopic view can be investigated.

In terms of performing tracing tasks with speed variation, the junior surgeons outperform the other sample group consistently (Fig. 5*b* and Fig. 8). This indicates that they may have better eye-hand coordination or more patience.

Performing the task in faster speed causes the variation of speed to be larger because it is more difficult for the hand to maintain or control the correct speed limit properly. This corresponds to observed increase of deviation for larger muscles activation.

References

[1]. W. T. Latt, U. X. Tan, E. S. Ananda, S. C. L. Ong, K. C. Veluvolu, C. Y. Shee, and W. T. Ang, “Design and Implementation of a Two Degrees-of-Freedom Micro-manipulation Assessment System” *Proc. IEEE Intl. Conf. EMBS*, Aug 2008, pp. 5640 - 5643.

[2]. John D. Lubahn, Brian G. Dickson, and Timothy Cooney, “Effect of Timolol vs. A Postural Orthotic on Hand Tremor During Microsurgery”, *J. Microsurgery* vol. 22, pp. 273–276, 2002.

[3]. Hemant M. Kocher, Jane Warwick, Reyad Al-ghnaniem and Ameet G. Patel “Surgical Dexterity After a ‘Night Out on the Town”, *ANZ J. Surgery* vol. 76, pp. 110–112, 2006.

[4]. Urso-Baiarda, F., S. Shurey and A. O. Grobbelaar, “Effect of caffeine on microsurgical technical performance”, *J. Microsurgery* vol. 27(2), pp. 84–87, 2007.

[5]. Elan D. Louis, “Kinetic tremor: Differences between smokers and non-smokers”, *J. NeuroToxicology* vol. 28 (2007), pp. 569-575.

[6]. Patricia A. Hsu and Brian C. Cooley, “Effect of Exercise on Microsurgical Hand Tremor”, *J. Microsurgery* vol. 23, pp. 323-327, 2003.

[7]. Emma Gowen and R. Chris Miall, “Eye–hand interactions in tracing and drawing tasks”, *Human Movement Science* vol. 25 (2006), pp. 568–585.

[8]. B. Safwat, E.L.M. Su, R. Gassert, C.L. Teo and E. Burdet, “The Role of Posture, Magnification, and Grip Force on Microscopic Accuracy”, *Ann Biomed Eng*, 2009 May; 37(5):997-1006.

[9]. Z. Bohdanecky, M. Indra, T. RadilL, “Manual Tracing Efficiency Contingent Upon Stimulus Shape and Performance Practice”, *Physiol. Res*. 45 (2): pp. 137-143, 1996.