Surgical Instrument Vibrations are a Construct-Valid Measure of Technical Skill in Robotic Peg Transfer and Suturing Tasks

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INTRODUCTION

Traditional surgical skill assessment relies on observation of a surgeon's performance, a method that is both subjective and time consuming. The growing demand for robotic minimally invasive surgery has increased the need for objective methods of assessing technical skill for surgical training [1,2]. Several prior skill assessment studies have analyzed the kinematic motion of the robot to calculate performance metrics such as economy of motion and instrument speed [3,4]. However, these metrics do not account for interactions between the instruments and the surgical environment.

One possible method of objectively accounting for the quality of these interactions and classifying instrument handling skills is to measure the transient mechanical vibrations of the robotic instruments. These vibrations primarily result from instrument contact with objects in the environment, such as collisions and needle hand-offs, with larger vibrations generally signifying *rougher* interactions. *Abrupt* movements of the surgical instruments also cause measurable vibrations. Our work on VerroTouch, a system for providing real-time auditory and haptic feedback of instrument vibrations [5], has shown that robotic instrument vibrations can easily be measured with low-cost accelerometers mounted on the patient-side robot.

Preliminary analysis of data collected in a previous study of VerroTouch [5] showed that instrument vibration magnitude is a construct-valid metric of technical skill for a needle passing task [6]. To determine whether this metric is construct valid for a wider range of training tasks, this paper analyzes the peg transfer and suturing tasks from that prior study.

MATERIALS AND METHODS

As fully detailed in [5], twelve surgeons performed three box-trainer-style tasks (peg transfer, needle pass, and suturing) with an Intuitive Surgical da Vinci S robot augmented with our system for measuring and feeding back instrument vibrations. Participants consisted of seven novice surgeons with no prior da Vinci experience and five experienced robotic surgeons (with experience ranging from 50 to 2400 cases). Each task was performed by each subject four times under different feedback conditions. This retrospective analysis focuses on the peg transfer and suturing tasks, and feedback condition is not considered.

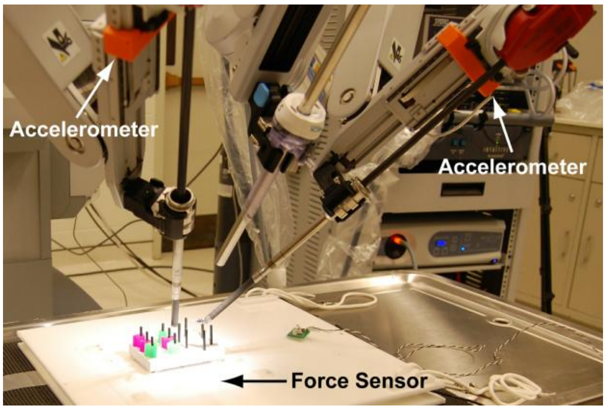

Fig. 1. A da Vinci S robot augmented with accelerometers that measure instrument vibrations. Task materials are mounted to the white board, which is equipped with a force sensor.

Accelerometers attached to the robot arms measured the high-frequency accelerations of the left and right needle driver instruments, and a force-torque sensor mounted within the task board measured the forces applied to the task materials (Fig. 1). For each trial we calculated the average root-mean-square (RMS) vibration magnitude of the two instruments and the RMS force applied to the task board over the duration of the task, as described in [5]. Only vibrations exceeding 0.2 m/s^2, the empirically determined noise ceiling of the sensors, were included in the RMS calculations. Video of each trial was recorded, and the completion time was noted.

To verify the skill level of the participants, two experienced robotic surgeons who participated in the study two years prior were recruited as raters; both were blinded to subject identity and experience level. The raters scored video recordings of the 48 suturing trials on paper surveys using a modified combination of the Objective Structured Assessment of Technical Skill (OSATS) global rating scales [7] and the Global Evaluative Assessment of Robotic Skills (GEARS) scale [8]. The following OSATS categories were used: *Respect for Tissue, Time and Motion, Instrument Handling,* and *Flow of Operation and Forward Planning*. The GEARS items used were *Depth Perception*, *Bimanual Dexterity*, *Efficiency*, *Force Sensitivity*, and *Robotic Control*. The peg transfer task was not rated due to the simplicity of the task.

Table 1. Comparison of RMS instrument vibrations, RMS forces, and time to completion for novice and experienced robotic surgeons doing peg transfer and suturing tasks. Suturing skill was also rated using OSATS and GEARS.

	Novice	Experienced	p value
Peg Transfer			
RMS Vib (m/s^2)	0.9 ± 0.2	0.8 ± 0.1	0.049
RMS Force (N)	3.3 ± 1.3	2.3 ± 1.2	<0.0001
Time (s)	121 ± 32	87 ± 21	<0.0001
Suturing			
RMS Vib (m/s^2)	0.8 ± 0.2	0.6 ± 0.1	0.023
RMS Force (N)	1.5 ± 0.8	1.0 ± 0.4	0.015
Time (s)	113 ± 24	60 ± 15	<0.0001
OSATS (%)	0.5 ± 0.1	0.8 ± 0.1	<0.0001
GEARS (%)	0.5 ± 0.1	0.8 ± 0.1	<0.0001

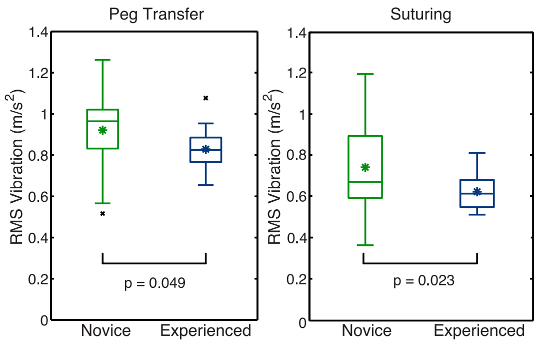

Fig. 2. Box plots of the average measured RMS instrument vibrations for the peg transfer and suturing tasks. The mean value for each group is marked with *, and outliers are indicated with an x. Experienced robotic surgeons caused significantly lower instrument vibrations than novices in both tasks (p-values indicated on plots).

Independent-sample t-tests were conducted on the task data to compare the instrument vibrations of novice and experienced surgeons. Applied force, completion time, and rated skill were also compared to determine whether differences existed between the two groups.

RESULTS

Experienced robotic surgeons recorded significantly lower instrument vibrations than the novice surgeons for both the peg transfer and suturing tasks, (Peg Transfer: $t(46) = 2.02$, $p = 0.049$, Suturing: $t(46) = 2.34$, $p = 0.023$). Box plots of the RMS vibration data for both tasks are provided in Fig. 2. Experienced surgeons also recorded lower RMS forces and task completion times, as seen in Table 1.

Blinded OSATS and GEARS evaluations verified that experienced robotic surgeons performed the suturing task with greater assessed technical skill than novices. Inter-rater reliability was very good, with an Intraclass Correlation Coefficient (ICC) of 0.80 (95% CI 0.71 – 0.86). Average skill ratings and results of the t-test are also found in Table 1.

DISCUSSION AND CONCLUSIONS

The presented results demonstrate that instrument vibrations, as measured by VerroTouch, are a construct-valid measure of technical surgical skill during robotic in vitro training tasks. Although differences in RMS vibration magnitude appear to be small for these tasks, some novices' slower coordinated actions may have resulted in lower vibrations for certain manipulation events. We believe overall skill level depends on multiple measures, so novices should improve their coordination while completing tasks quickly, efficiently, with low forces, and with low instrument vibrations.

In contrast to the kinematic measures recorded by the robotic system, instrument vibrations indicate the quality of instrument handling and interaction with the operative environment. Furthermore, evidence that visual feedback of skill measures may increase a surgeon's ability to improve their performance [4] suggests that the real-time audio and haptic feedback of instrument vibrations provided by VerroTouch could also enhance the training of robotic surgeons. Studies to verify this are currently in progress.

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