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A Virtual Reality Training Program for Improvement of Robotic Surgical Skills

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Abstract. The purpose of this study was to use a simulated virtual reality environment for training of surgical skills and then to identify if the learning that occurred was transferable to a real world surgical task. The virtual surgical tasks consisted of bimanual carrying, needle passing and mesh alignment. In this ongoing study, the experimental group (n=5) was trained by performing four blocks of the virtual surgical tasks using the da Vinci surgical robot. Pre and post training, all subjects were tested by performing a suturing task on a "life-like" suture pad. The control group (n=5) performed only the suturing task. Significantly larger pre and post differences were revealed in time to task completion ($p<0.05$) and total distance travelled by the dominant side instrument tip ($p<0.01$) in the experimental group as compared to the control group. These differences were specific to the suture running aspect of the surgical task. In conclusion, virtual reality surgical skills training may produce a significant learning effect that can transfer to actual robot-assisted laparoscopic procedures.

Keywords: Virtual Reality, da Vinci Robotic Surgical System, Laparoscopic Training

1. Background

Despite significant increases in robot-assisted surgeries, robotic surgical training programs are not widely adopted [1]. Virtual Reality (VR) has been used to improve training for manual laparoscopy and to give surgeons superior performance in the operating room [2]. VR simulations can also provide user-friendly, attractive, easily accessible and inexpensive environments to learn robotic surgical skills. In our past work, we have shown that robotic surgical skill learning through VR simulations is comparable with real world surgical skill improvement tasks [3, 4, 5]. Therefore the next logical step was to implement the VR simulations as part of a training program and determine the effect of learning on a common real-world surgical task – *suturing*.

2. Methods

Subjects: Ten young healthy student volunteers from the University of Nebraska Medical Center and the University of Nebraska at Omaha participated in this ongoing study. Subjects were randomly assigned to either the experimental (VR) group or the control group.

Training Tasks: Subjects performed three tasks in a VR environment (Figure 1): bimanual carrying (BC), needle passing (NP) and Mesh Alignment (MA). In the BC task, they simultaneously picked up simulated pieces from simulated metal caps and placed them in two other simulated metal caps. In the NP task, they passed a simulated surgical needle through a simulated tube. In the MA task, a virtual rolled-up mesh was opened up by the simulated arms of the robot and placed on a pre-marked virtual task platform. The tasks have been designed to mimic training of real-life surgical skills in terms of their cyclic nature (BC task), decision-making skills (determining location of touch sensors to unroll the mesh in the MA task) and grasping and release skills (both BC and NP tasks).

Testing Task: Pre and post the VR training tasks, all subjects performed three trials of a procedure of repairing an enterotomy on a life-like suture pad (Figure 2). The procedure consisted of using the Da Vinci Surgical System (Intuitive Surgical, CA) for making three single knots, five running passes followed by three single knots again between predefined locations on the suture pad.

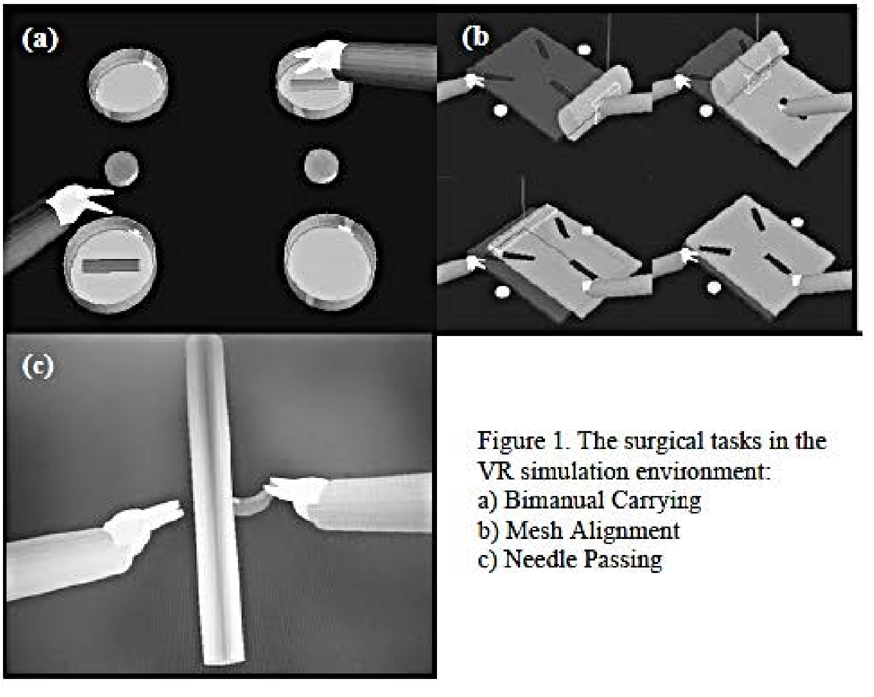


Figure 1. The surgical tasks in the VR simulation environment:
a) Bimanual Carrying
b) Mesh Alignment
c) Needle Passing

Experimental protocol: Subjects in the VR group performed the three tasks in four blocks. In each block, each of the three tasks was performed five times. The order of tasks was randomized within each block. The Webots software (Cyberbotics, Lausanne, Switzerland) was used to build the VR environment which was driven by kinematic data streaming in real-time from the operating console of the da Vinci robot. Subjects in the control group performed only the pre and post test before and after a gap of 2.5 hours (the average time to complete the VR training).

Data Collection and Analysis: Kinematics of the da Vinci surgical instrument tips was sampled at 100 Hz. Analysis of the robot data included time to task completion and total distance travelled by the instrument tip of the dominant side.

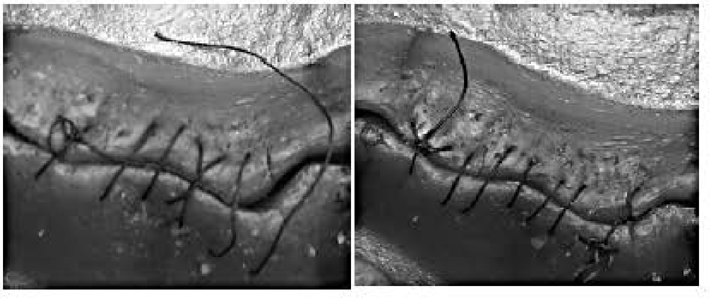
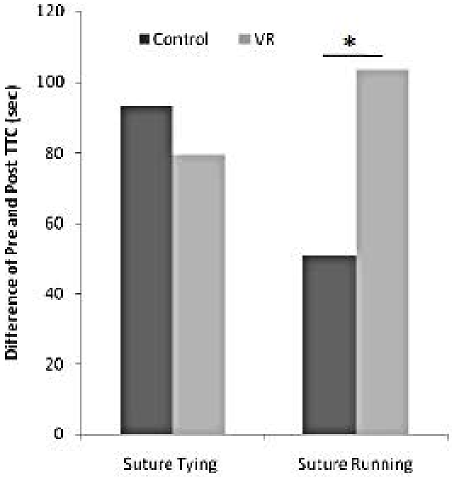


Figure 2. Suture tying and running performance of a subject for pre-testing (left) and post-testing (right).

3. Results

Our results showed that after performing four blocks of simulated surgical skills training, the VR group had a significantly larger change in time to task completion ($p<0.05$) between pre and post suture running aspect of the testing task (Figure 3). These differences were also reflected in change in the total distance travelled by the instrument tip of the dominant side ($p<0.01$) between the pre and post suture running tests on the suture pad (Figure 4). This measure was not significantly different for the non-dominant side ($p>0.05$). The suture tying task was not significantly different for either the time to task completion or the total distance travelled by the instrument tip between the two groups.



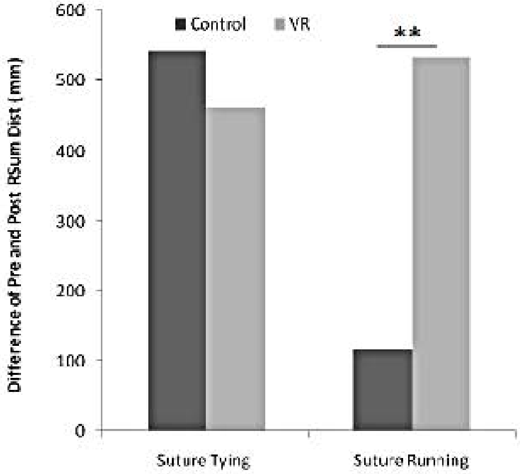


Figure 3. Improvement in time to task completion between pre and post-suture tying and running performance for the two groups.

Figure 4. Improvement in distance travelled by the dominant side instrument tip between pre and post-suture tying and running performance for the two groups

4. Discussion

Our results showed that simulated surgical skills training in a VR environment can cause significant improvement in surgical skill performance on a real world surgical task. Improvement in performance using VR simulators has been shown previously [1] and validation of VR environment with real world surgical skills training has also been shown previously [3-5]. However, this study showed that VR training of surgical skills could transfer to real world surgical task. Differences in dominant and non-dominant side performance in robotic surgical tasks have been shown previously [6]. The VR training caused significant improvement in suture running aspects of the task but not in suture tying tasks. This could be due to the simplistic nature of the VR environment.

5. Conclusions

Our results are highly encouraging in indicating that training with simulated surgical tasks may result in improvement of actual surgical skills. However, more research and results from a larger sample size are needed to confirm our findings. Moreover, further improvement of the virtual environment can enhance the learning effect.

6. Acknowledgements

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Consistency of Performance of Robot-Assisted Surgical Tasks in Virtual Reality

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Abstract. The purpose of this study was to investigate consistency of performance of robot-assisted surgical tasks in a virtual reality environment. Eight subjects performed two surgical tasks, bimanual carrying and needle passing, with both the da Vinci surgical robot and a virtual reality equivalent environment. Nonlinear analysis was utilized to evaluate consistency of performance by calculating the regularity and the amount of divergence in the movement trajectories of the surgical instrument tips. Our results revealed that movement patterns for both training tasks were statistically similar between the two environments. Consistency of performance as measured by nonlinear analysis could be an appropriate methodology to evaluate the complexity of the training tasks between actual and virtual environments and assist in developing better surgical training programs.

Keywords: Virtual Reality, da Vinci Robotic Surgical System, Nonlinear Analysis

1. Background

Robot-assisted surgery has grown significantly over the last 15 years; it provides superior depth perception, increased dexterity [1] and decreased training time for surgical residents [2, 3]. Thus, new surgeons and residents are eager to learn robot-assisted laparoscopic techniques [4]. Virtual reality (VR) simulations can provide surgeons and residents a risk-free environment where they can repeatedly practice robot-assisted surgical techniques. In our pervious studies, we have successfully validated several robot-assisted surgical tasks such as bimanual carrying [5, 6] and mesh alignment [7] in VR.

However, this validation was conducted using measures such as time to task completion and distance traveled, without any regard for how consistent performance can be within VR. Here we used a nonlinear measure, the largest Lyapunov Exponent

(LyE) that allow us to evaluate movement variability over time, in order to investigate consistency of performance of robot-assisted surgical tasks performed in both the da Vinci surgical robot and our virtual reality equivalent environment. We expected that this approach could allow us to better evaluate consistency of performance in both actual and virtual environments and further validate our VR simulations.

2. Methods

Eight right-handed medical students (24.8 ± 5.6 years old) with no prior experience using the da Vinci Surgical System (Intuitive Surgical, Inc., Sunnyvale, CA.) were recruited to participate in this study. The participants were instructed to complete three trials of a Bimanual Carrying (BC) task (Fig. 1) and five trials of a Needle Passing (NP) task (Fig. 2) in both the actual and the virtual environments. The virtual BC (Fig. 1a) and virtual NP (Fig. 2a) tasks were compared to their corresponding actual tasks. For the BC task, all participants controlled the surgical robot arms to simultaneously pick up plastic pieces from metal caps and place them in two other metal caps 60 mm away(Fig. 1b). For the NP task, they passed a 26 mm surgical needle through 6 holes of a latex tube (Fig. 2b).

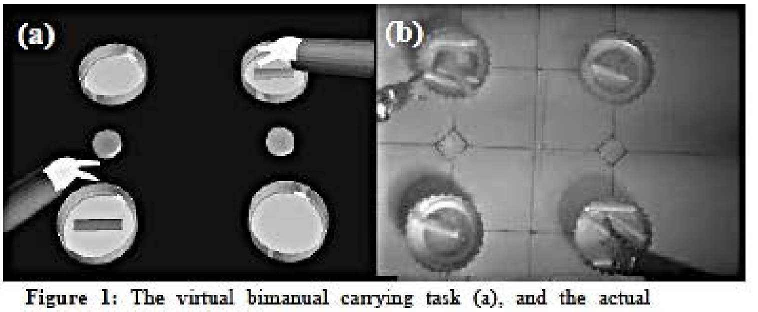

Figure 1: The virtual bimanual carrying task (a), and the actual bimanual carrying task (b).

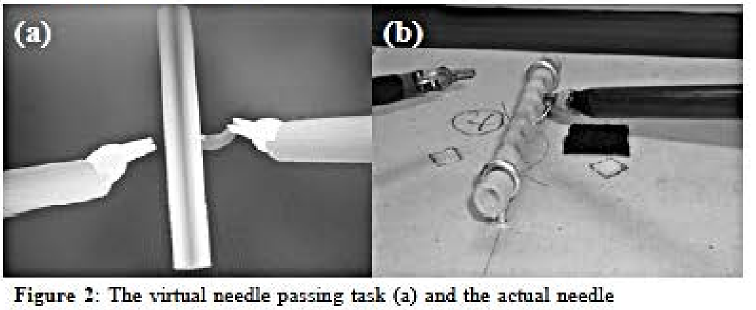

Figure 2: The virtual needle passing task (a) and the actual needle passing task (b).

The VR environment was constructed using Webots (Cyberbotics, Ltd., Lausanne, Switzerland). The da Vinci surgical instruments and training platform were modeled as 3D objects using SolidWorks (SoldWorks Corp., Concord, MA). This simulation was driven by kinematic data from the robotic operating console sampled at 100Hz. The virtual images were then overlapped on the screen inside the console.

Consistency of performance was evaluated from the movement trajectories of the surgical robotic instrument tips using the LyE. The LyE evaluates the amount of divergence present in the movement trajectories (Fig. 3), and examines the exponential separation of nearby trajectories in the reconstructed state space (Fig. 3A-C) [8, 9]. Paired t-tests were used to compare the LyE group mean values between the actual and the virtual environments for both tasks.

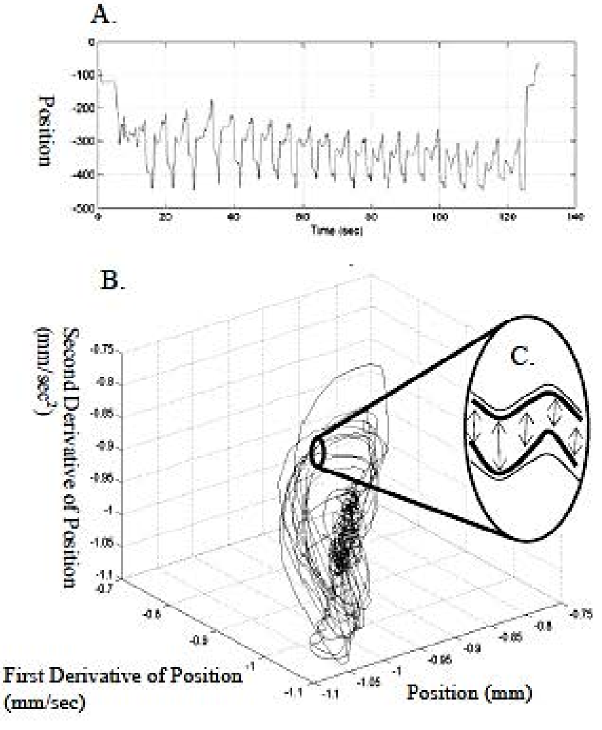

Figure 3: A) Two time series of the horizontal displacement of the NP task from the surgical instrument tips. B) From these time series state spaces in three dimensions are created. C) A section of the state space where the divergence of neighboring trajectories is outlined.

3. Results

There were no significant differences for the LyE between the actual and virtual environments in both bimanual carrying (BC) ($p = 0.90$) and needle passing (NP) tasks ($p = 0.12$) (Fig. 4).

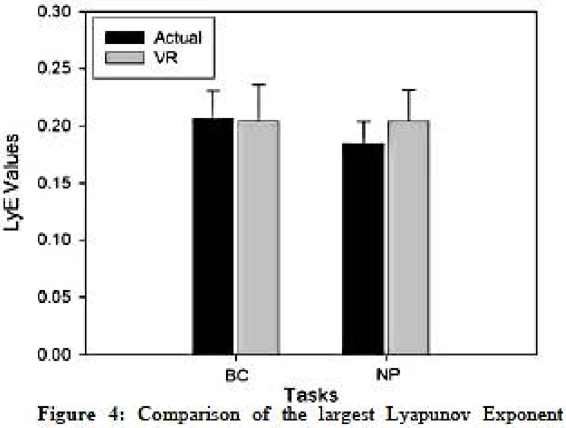

Figure 4: Comparison of the largest Lyapunov Exponent (LyE) values between the actual and VR environments for BC and NP tasks.

4. Discussions

In this study, we investigated consistency of performance of robot-assisted surgical tasks performed in both the da Vinci surgical robot and a virtual reality equivalent environment using the LyE. The LyE examined the amount of divergence present in the movement trajectories of the surgical instrument tips over the entire time that the participants performed the BC and the NP tasks with the actual da Vinci surgical robot and the virtual simulated environment. Practically less divergence signifies more consistency and no variability in the movement trajectories.

Therefore, the lack of significant differences found in the LyE values suggested that the amount of divergence present in the movement trajectories of the surgical instrument tips was similar in both environments. Therefore, the performance of the surgical skills selected was consistent between the two environments.

This further validated our VR environment and provided the foundation to utilize this approach in future studies where we will evaluate training protocols for surgeons and residents. We also plan to improve the complexity of our VR environment for the da Vinci surgical robot incorporating animal and common human procedures (i.e. prostatectomy).

5. Conclusions

Consistency of performance as measured by nonlinear analysis could be an appropriate methodology to evaluate the complexity of the training tasks between actual and virtual environments and assist in developing better surgical training programs.

6. Acknowledgements

This work was supported by the Nebraska Research Initiative and the Center for Advanced Surgical Technology, University of Nebraska Medical Center.

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