The Role of Haptic Feedback in the Training and Assessment of Surgeons using a Virtual Environment

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Abstract

Haptic feedback plays an important role in the development of high fidelity virtual training environments for surgeons. The coupling of virtual simulation environments with instrumented data collection methods would allow quantification of performance. This work demonstrates the use of such a system to achieve quantitative evaluation of suturing performance. Force application, time to task completion, length and straightness of the suture have been measured. The paper concludes that performance improved over trials in terms of time to complete and accuracy of the length of suturing. Force feedback affected force application, task completion time and the straightness of suturing.

1. Introduction

There is increasing interest in the development of virtual reality (VR) systems for the training of surgeons. VR offers many benefits to training. These include a reduction in costs and associated patient risk, flexible access to training material and the possibility of self-paced learning [1][2]. The trainee is able to develop surgical skills to a proficient level before transferring them into the operating theatre. The fidelity of the VR simulation is crucial to ensure that skills transfer effectively.

Strong sensory feedback is an important requirement for realistic surgical simulation [3]. Current systems vary in the quality of the visual and tactile information provided to the user. This is due to the many technical challenges to ensure accuracy [4][5].

The ability to identify tissue properties and apply the appropriate handling technique is an important skill for the trainee to acquire [6]. A realistic simulation should provide the user with force feedback in order for the surgeon to be able to detect tissue components. These forces are small and exact, while difficult to recreate [3].

Similarly, in order to produce virtual tissue, knowledge is required of real tissue properties and their respective handling forces. Methods to collect force application data therefore are required. [7].

SensAble's PHANToM desktop device has been incorporated into many current simulation designs [8][9]. It provides the user with force feedback when virtual objects are manipulated.

Using the PHANToM, this paper aims to demonstrate the effect of force feedback information on performing a basic surgical task. The effect of feedback is then related to force application and improvement of the task.

2. Method

2.1 Participants

Twenty students took part in the experiment. They had an average age of twenty -five years (range eighteen to forty-five). They were all right hand dominant. Each undertook a total of ten trials.

2.2 Equipment

For the experimental setting, the SensAble PHANToM desktop unit [10], run in Windows NT 4.0, was utilised in conjunction with a suturing simulation [11]. The device provides resistance to the users movements with 3 degrees of freedom force feedback and 6 degrees of freedom position sensing.

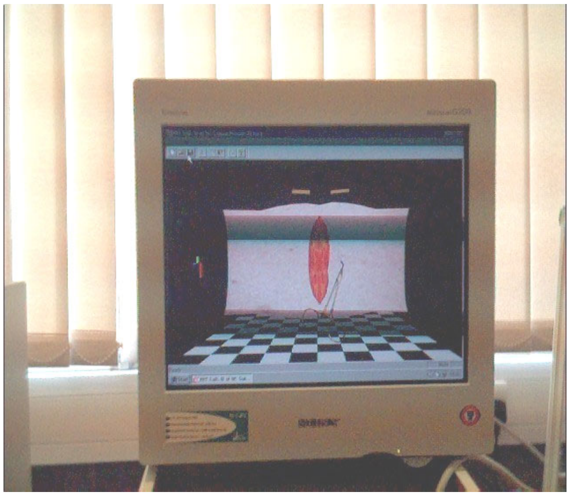

Figure 1: The display of the suturing simulation.

The suturing simulation consisted of a virtual wound, needle holders and needle and thread. Sutures could be placed in the skin excision. The tissues deformed in a manner similar to actual tissue, when pressure was applied. Force feedback was provided to the user through the haptic end-effector of the SensAble PHANToM device.

Figure 2: The experimental setting: the needle-holders attached to the SensAble PHANToM device.

A pair of needle holders was loosely attached to the end-effector. As a consequence, they moved in correspondence to the virtual instruments. The needle holders were instrumented with strain gauges to allow measurement of the forces applied during their manipulation. This data was fed directly into Microsoft Excel, to be further formatted for statistical manipulation.

2.3 Procedure

The task was demonstrated and explained to each subject by the experimenter. Each participant then performed two test sutures to familiarise themselves with the task and the experimental setting.

The participants were asked to form one suture across the skin excision. It was specified that the point of needle insertion should be approximately 2cm off the edge of the excision. This point was marked on the simulation. Once the suture had been formed the thread was pulled tight to bring the skin edges together with minimum overlap and tissue distortion. The target requirement was a 4 cm straight stitch.

Data collection began at the first movement of the needle by the participant. Time was measured automatically. The Daz Wizard program was initiated concurrently to allow the force measurement from the needle-holders. After each trial the resulting stitch was projected and traced onto acetate.

Each participant completed 10 trials. In each, a full suture procedure was formed in a clear wound. The experimental time allowed for each trial was limited to 40 seconds. The participants were assigned to one of two conditions. For the first the PHANToM device provided force feedback to the user and for the second force feedback was not applied.

3. Results

The results were analysed to determine the effect of force feedback on task performance. The effect of trial was further analysed to investigate how performance changed over time.

3.1 Effect of trial

A paired sample t-test revealed that over the trials the time to complete a stitch was significantly reduced ($p=0.01$). There was a significant change in the length of the stitches ($p=0.04$). The other measures were unaffected by trial. Detailed measurements for trial 1 and 10, in relation to their average (overall), can be seen in table 1.

Condition	Trial	Time (s)		Force (N)		Length (cm)		Straightness score	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Force Feedback provided	1	28.24	12.87	5.59	2.36	2.19	1.49	4.6	1.96
	10	10.89	1.98	5.76	2.01	2.92	0.74	5.4	0.7
	Overall	20.17	12.48	5.67	2.14	2.52	1.19	5	1.49
Force Feedback withheld	1	22.79	9.74	3.94	1.58	2.27	1.39	4.6	1.84
	10	18.98	11.65	4.38	2.19	3.39	1.48	5.7	0.67
	Overall	20.53	10.49	4.16	1.87	2.8	1.47	5.15	1.46

Table 1: Effect of trial and condition.

3.2 Effect of condition

An independent samples t-test revealed that the presence of force feedback significantly affected the force applied during suture production (p=0.021). A greater level of force was applied when the feedback was activated. The time to complete the stitch was affected by the presence of force feedback (p=0.048). Feedback resulted in an overall reduction of stitch completion time. Using the Mann-Whitney test, straightness was affected by feedback (p=0.018). With feedback higher scores for straightness were achieved.

4. Discussion and conclusions

Performance has been shown to improve over trials. This is shown by a reduction in the time to complete and improved accuracy of the length of the stitch.

To increase the realism of surgical simulations, force feedback should be provided during manipulation of virtual tissue. The results indicate that force application increases as does time to complete, with the provision of force feedback. This would be expected in order to overcome the haptic effects. The affect on force application demonstrates the importance of accurate haptic feedback. Virtual tissues should respond appropriately to allow anticipation of real tissue behaviour and for skills transfer to take place. Future work should demonstrate how force application is affected by variations in the level of the force feedback.

The importance of collecting force application data for task performance has been demonstrated. This information has been derived through instrumented collection of data in a simulation environment. The advantage of an external method of instrumented data collection is its transferability between the operating theatre and simulated models. Determining the appropriate levels of force application for particular tissues provides a means of assessing the validity of a simulation, enables provision of feedback during training and supports the establishment of benchmark levels for assessment.

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