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Ergonomic factors on task performance in laparoscopic surgery training

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ABSTRACT

This paper evaluates the effect of ergonomic factors on task performance and trainee posture during laparoscopic surgery training. Twenty subjects without laparoscopic experience were allotted into 2 groups. Group 1 was trained under the optimal ergonomic simulation setting according to current ergonomic guidelines (Condition A). Group 2 was trained under non-optimal ergonomic simulation setting that can often be observed during training in a skills lab (Condition B). Posture analysis showed that the subjects held a much more neutral posture under Condition A than under Condition B ($p < 0.001$). The subjects had less joint excursion and experienced less discomfort in their neck, shoulders, and arms under Condition A. Significant difference in task performance between Conditions A and B ($p < 0.05$) was found. This study shows that the optimal ergonomic simulation setting leads to better task performance. In addition, no significant differences of task performance, for Groups 1 and 2 using the same test setting were found. However, better performance was observed for Group 1. It can be concluded that the optimal and non-optimal training setting have different learning effects on trainees' skill learning.

1. Introduction

In the last two decades minimally invasive surgery (MIS) has been gaining in acceptance and popularity. Laparoscopic cholecystectomy became a golden standard procedure with proven benefits (Matern, 2009; Kaya et al., 2008). However, drawbacks of the laparoscopic approach such as lack of tactile perception and limited degree of freedom for manipulating the instruments remain. Therefore, proper design of the instruments and operating room layout has now become more critical in order to avoid fatigue and human errors. The ergonomic factors are thus of increasingly importance for MIS (Berguer, 2006).

Safe performance of laparoscopic surgical procedure requires adequate training preferably in a well-equipped skills lab, within a structural training curriculum. Current states of simulation training in surgery and listing of available modalities have recently been presented (Jakimowicz and Fingerhut, 2009; Jakimowicz and Jakimowicz, 2011).

Box trainers are highly versatile, relatively inexpensive and offer realistic haptic feedback and are thus attractive for laparoscopic trainings purposes. Basically such a training device consist of a box in which physical objects (like artificial organs) are positioned. The trainee can practice various skills and tasks, such as the eye-hand coordination and camera navigation (Botden et al., 2008).

Depending on the type of training, a variety of objects can be positioned in the box. Novice trainees start practicing by positioning beans; while more advanced trainees perform procedures on artificial, living or cadaver organs/tissues. Lights, instruments and medical appliances can be used to simulate the clinical operating room as good as possible. Because the trainee is practicing on physical structures it is valuable to use the standard clinical instruments so as to experience and train the haptic feedback. For this reason, it is meaningful to investigate the ergonomic factors of the simulation setting with box trainer, with an eye for further improvements of existing modalities.

It is common that many simulation setups in skills labs are sub-optimal from an ergonomic point of view, such as table height that cannot be adjusted, monitors that cannot properly be positioned. Also, the workspace and the target location cannot assure a certain range of intra-corporal/extra-corporal instrument length ratio. Last but not least, the optical axis-to-target view angle is often randomly chosen.

In this research, two performance conditions were set for training and testing subjects. One was an optimal ergonomic condition according to literatures (Hanna et al., 1997; Berguer et al., 2002; Matern et al., 2001; Emma et al., 2000), and the other was

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a non-optimal ergonomic condition that can often be observed in the skills lab. The goal of this study is to investigate the influence of ergonomic factors on task performance during laparoscopic training with a box trainer, and to evaluate the trainee posture under these two conditions.

2. Materials and methods

2.1. Equipment setup

A COVIDIEN box trainer equipped with one adjustable camera (WatecWAT-240 VIVID) was used to capture the inside image. Two shadowless LED lamps inside were used as light source, and two holes ($D = 10$ mm) in the top cover were used as entrance port. The optical axis-to-target view angle could be set by user.

Two adjustable tables were used: one for adjusting the monitor height, the other for adjusting the operating surface height. A monitor (Acer AL1732) was used to display the inside image. Three cameras (SONY Handycam Hi8) were placed in front, left and right side at an angle of 90° of each subject, to record their actions. Images of these three cameras and one adjustable digital camera used as a 0° angled endoscope were mixed with a Digital Color Quad Processor (Conpon SC-CQPDVR (V1) KIT1) and connected with a desktop. Fig. 1 shows the position of cameras.

Two experiment conditions were considered. Group 1 was trained under optimal ergonomic simulation setting according to current ergonomic guidelines (Wauben et al., 2006; Marcos et al., 2006; Zehetner et al., 2006), i.e. Condition A. Group 2 was trained under non-optimal simulation setting as often be able to observed in a skills lab simulation setting (Condition B). Fig. 2 shows an awkward posture of a surgeon during a training course. She has to lift her arms to perform task although she already stand on steps. Also the extra-corporal instrument length was longer than the intra-corporal length.

Fig. 3 (left) shows the optimal ergonomic simulation setting (Condition A). The ergonomically optimal monitor position was set as Condition A according to various sources in literatures (Hanna et al., 1997; Berguer et al., 2002; Matern et al., 2001; Emma et al., 2000; Burgess-Limerick et al., 2000; Jaschinski et al., 1998; Turville et al., 1998). The monitor was at a distance of 0.6 m apart from the subjects' eyes. The monitor height (from the middle of the screen to the ground) was between the operating surface and eye-level height, and the monitor was inclined (to a maximum of 15°) as preferred by the subjects. The optimal operating surface height was

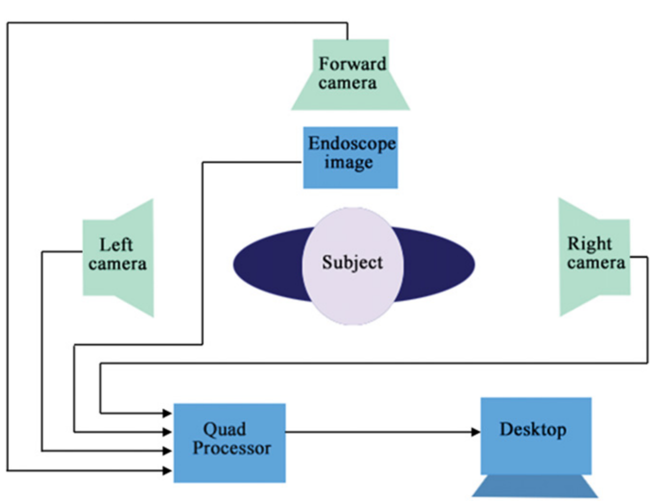

Fig. 1. Schematic diagram set up of cameras. Three cameras were used to record joints angle, one inside camera was used as endoscope to record inside images.

80% of the elbow height and the table was positioned in 20° tilt (Van Veelen et al., 2002). The optical axis was perpendicular to the target plane ($\beta = 90°$) (Hanna and Cuschieri, 1998, 2008). The intra-corporal instrument length was longer than the extra-corporal length (intra-corporal/extra-corporal ratio > 1) (Emma et al., 2000). Under this condition, every trainee can keep a neutral posture when performing the task.

Fig. 3 (right) shows a non-optimal ergonomic simulation setting that can often be observed during training in skills labs (Condition B). The monitor was at a distance of 100 cm apart from the subjects. The monitor height is 1.1 times of the eye-level height. The operating surface height was set equal to the elbow height, and the table was horizontally positioned. The optical axis-to-target view angle was 45°. The intra-corporal instrument length was shorter than the extra-corporal instrument length (intra-corporal/extra-corporal ratio < 1). Under this condition, every trainee was performing the task in an awkward posture. The middle of Fig. 5 shows an awkward posture of one trainee when performing task, He has to raise his shoulder and elbows to manipulate the instruments, this could cause serve discomfort after a few minutes.

2.2. Subjects and tasks

Experienced laparoscopic surgeons who have adapted to a certain work posture were excluded from this study. Twenty subjects (9 males and 11 females) aged from 22 to 31 without laparoscopic experiences were allotted into two groups (Groups 1 and 2). Their body height (9 males body height: 179 cm ± 6 cm; 11 females body height: 167 cm ± 9 cm), eye-level and elbow height were measured. Every subject had to perform two tasks.

In task 1 laparoscopic suturing was simulated by threading tiny tubes (Matern et al., 2005). Several tiny plastic tubes with a diameter of 5 mm were sequentially stringed with a curved needle using two needle holders (26173 KL, Karl Storz, Germany). The number of tubes stringed by every subject in 5 min was counted.

Task 2 was supplied by COVIDIEN. The suture (polypore 2–0) was threaded through 8 eyelets on a training block with a curved needle using two needle carriers. The suture path was indicated by the arrows. The completion time and the number of incorrect actions were recorded. Here the incorrect actions included needle dropping, ring missing and wrong suturing direction.

In agreement with Derossis (Derossis et al., 1998), a timing score was defined based on the completion time and a cutoff time of 900 seconds. A timing score can then be calculated by:

$$\text{Timing score} = 900[\text{s}] - \text{completion time}[\text{s}] \quad (1)$$

The performance of task 2 was evaluated by the timing score and the penalty score. The penalty score was obtained by the sum of the points for incorrect actions: 10 point for each needle dropping and ring missing, 5 point for each wrong suturing direction. The total score can then be given by:

$$\text{Total score} = \text{timing score} - \text{penalty score} \quad (2)$$

The performance is in direct proportion to the total score in this method. In other words, a task with a certain completion time and fewer mistakes gains a higher score than that with more mistakes.

2.3. Experiment procedure

Group 1 was trained with the box trainer under Condition A. Their performance was first assessed under the optimal ergonomic setting (G1A), then under the non-optimal ergonomic setting (G1B).

Group 2 was trained with the box trainer under Condition B. Their performance was first assessed under a non-optimal