Mental and physical workload in laparoscopic surgery

By

Massoud Hemida Geryane

A thesis submitted for the Degree of
Doctor of Philosophy of the University of London
and the
Diploma of Imperial College

Department of Bio-surgery and Surgical Technology
Imperial College London

September 2005

ABSTRACT

Laparoscopic surgery imposes a complex interface between the surgeon and the operating field. Therefore; such techniques require a complex cognitive and motor performance that increases surgeon's mental and physical workload. This thesis deals with ergonomic factors that govern task performance in laparoscopic surgery. Factors related to the imaging system, surgeons training and task difficulties were investigated. Physical workload was measured with electromyography and infra red motion tracking system. Mental workload measures were heart rate, heart rate variability, electrodermal activity and endogenous eye blinking rate. Performance outcome measures were execution time, suture error placement score, and knot quality score. Interpretation of physical workload, mental workload and performance outcome measures revealed that large image is superior to the small image with small image is best placed at 100 cm viewing distance, whereas; for the large image ranged from 60 cm to 100 cm. Gaze down set-up decreased physical and mental workload compared to eye level set-up. The two dimensional display was superior to three dimensional imaging in terms of mental workload. Training decreased subjects' physical and mental workload. Different steps of surgical procedures impose various levels of mental workload on surgeons. For instance, dissection of Calot's triangle is the most mentally demanding step during laparoscopic cholecystectomy.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GLOSSARY

Antimesenteric border: The border of the bowel opposite to the border where the blood supply enter the bowel.

Azimuth angle: The angle between the optical axis of the laparoscope and the laparoscopic instrument.

Calot's triangle: The triangle formed by the cystic duct, common hepatic duct and lower border of the liver.

Cystic artery: The arterial blood supply to the gallbladder.

Cystic duct: The duct connecting the gallbladder to the main biliary tree

Creation of pneumoperitoneum: Introducing the Co_2 gas to the patient's abdominal cavity.

Elevation angle: The angle between the laparoscopic instrument and the horizontal plane.

Entrotomy: An opening created in the bowel.

Intracorporeal knot tying: Tying a knot inside the abdominal cavity or the trainer box using laparoscopic instruments.

Laparoscopic cholecystectomy: Removal of gallbladder from the liver using laparoscopic technique.

Laparoscopic appendecectomy: Resection of the falciform appendix using a laparoscopic technique.

Manipulation angle: The angle between two laparoscopic instruments.

LIST OF ABBREVIATIONS

ADEPT: Advanced Dundee Endoscopic Psychomotor tester.

CCD: Charged Coupled Device.

DEPT: Dundee Endoscopic Psychomotor tester.

EOG: Electrooculogram

EMG: Electromyogram.

ES: Erector spinae muscle.

GA: Gaze angle.

HA: Head angle.

HR: Heart rate.

HRV: Heart rate variability.

Hf: High frequency band of the heart rate variability.

HFn: Normalised high frequency band of the heart rate variability.

HRA: Human Reliability Assessment system.

ICSAD: Imperial College Surgical Assessment Device.

Lf: Low frequency band of the heart rate variability.

LFn: Normalised low frequency band of the heart rate variability.

Lf/Hf: Low frequency-high frequency ratio.

MVC: Maximum Voluntary Contraction.

Neck-v: Neck angle relative to the vertical.

Neck-b: Neck angle relative to the body.

MIST-VR: Minimally Invasive Surgical Trainer-Virtual Reality system.

OCHRA: Observational Clinical Human Reliability Assessment system.

RMS: Root mean square.

SCL: Skin conductance level.

SRT: Space relation test.

STC: Sternocleidomastoid muscle.

Tb: Thoracic bending angle.

Dedicated to

my family for their sacrifices and support

ACKNOWLEDGEMENTS

I am greatly indebted to Mr George Hanna, Reader in Surgery, at the Department of Biosurgery and Surgical Technology, Imperial College, for his guidance, suggestions, valuable comments and support during the study, preparation of the thesis and writing the manuscripts originated from the project. I would like to express my gratitude to Professor Sir Alfred Cuschieri, Cuschieri Skills Centre, Ninewells Hospital and Medical School, for giving me the opportunity to carry out this project in the UK. I would like to thank Dr Simon Ogston, Lecturer in Medical Statistics, Department of Epidemiology and Public Health, Ninewells Hospital and Medical School for his statistical advice. Thanks are also extended to Professor Zidan Bader, Professor A Aljali, Mr S Bader, Mr A Mesalati, Mr M Moftah, Mr A Rabti, Mr T Mejresi, Department of General Surgery II, Tripoli Medical Centre for their help in the conduction of the clinical part of the project. I am very grateful to my colleagues Abd Alsalam Alhamrouni, Benji Tang, Pradeep Patil and Sopark Manasnayakorn for their friendship and support.

DECLARATION

I declare that this thesis has been composed by myself under the supervision of Mr. George Hanna, Reader in Surgery, Department of Biosurgery and Surgical Technology, Imperial College London and Professor Sir Alfred Cuschieri, Cuschieri Skills Centre, Ninewells Hospital and Medical School, University of Dundee. This thesis is a record of work which has not been submitted previously for a higher degree.

Massoud Hemida Geryane

September 2005

PRESENTATIONS TO LEARNED SOCIETIES

1. **Geryane MH**, Cuschieri A, Hanna GB. Effect of two and three-dimensional imaging on mental workload in laparoscopic surgery. European Association of Endoscopic Surgeons, 12th International Congress of Endoscopic Surgery, Barcelona, June 2004.
2. **Geryane MH**, Cuschieri A, Hanna GB. The effect of gaze down on muscle workload during laparoscopic task performance. European Association of Endoscopic Surgeons, 12th International Congress of Endoscopic Surgery, Barcelona, June 2004.
3. **Geryane MH**, Cuschieri A, Hanna GB. Surgeon's mental workload in endoscopic surgery is influenced by image size and viewing distance. European Association of Endoscopic Surgeons, 13th International Congress of Endoscopic Surgery, Venice, June 2005.
4. **Geryane MH**, Cuschieri A, Hanna GB. Effect of image size and viewing distance on surgeon's physical workload during laparoscopic task performance. European Association of Endoscopic Surgeons, 13th International Congress of Endoscopic Surgery, Venice, June 2005.

CHAPTER ONE

LITERATURE REVIEW

1. LITERATURE REVIEW

1.1 Laparoscopic surgery

Laparoscopic surgery aims to minimise the trauma to the patient without compromising the safety and efficacy of the treatment compared with traditional open surgery. Therefore laparoscopic surgery makes patients recover more quickly, which reduces hospital stay and allows more rapid return to full activity and work. Currently laparoscopic procedures are performed by creating a roomy space in the abdominal cavity of the patient using carbon dioxide. Carbon dioxide introduced in the patient's abdomen using automatic insufflator. The insufflator activates and delivers gas automatically when the intra-abdominal pressure falls because of gas escape or leakage from the ports. After insufflation of carbon dioxide in the patient's abdomen, ports (5mm-10mm in diameter) are introduced as access points for the laparoscopic instruments (35-40 cm in length). Starting with the laparoscope surgeon introduces the required laparoscopic instruments in the patient's abdomen through the ports. In this type of surgery surgeons work from displayed images of the operative field rather then reality. The laparoscopic imaging systems consist of light source and cables, laparoscope, camera and image display system.

- Light sources and cables:

Two types of light source are in use: xenon and metal halide (halogen).

- Laparoscopes:

Currently, most laparoscopes used in laparoscopic surgery are of the rigid viewing type based on the Hopkins rod-lens system (2). These laparoscopes vary in diameter and in their direction of view. In laparoscopy, the 10 mm laparoscopes with zero (forward viewing) or 30° and 45° forward oblique directions (view angles) are most commonly used.

- Charged couple device cameras:

The camera system has two components: the head of the camera, which is attached to the ocular of the laparoscope, and the controller, which is usually located on the trolley along with the monitor. The camera head consists of an objective zoom lens that focuses the image of the object on the chip. The chip has light sensitive photoreceptors that generate pixels by transforming the incoming photons into electronic charges. Laparoscopic cameras are divided into single chip and three chip cameras. The three chips camera system gives a higher resolution and better image quality because the pixel number is three times than the single chips system.

- Image display systems:

Currently images are viewed on high resolution television monitors mounted on trolleys that also house the light source, camera control unit and insufflator. The position of the monitor in relation to the operator is important.

As laparoscopic surgeons rely on image display systems and technology in addition to operator skill it should be considered that: (1) these techniques are technology dependent in that the procedure cannot be performed if the imaging system fails; (2) the image is two dimensional, and thus the operator has to process the image and monocular depth cues mentally to identify the target structures and perform precise manipulations; (3) the visual and the motor axis of the operator are no longer aligned, and with the current television monitor display, the image is far removed from the actual operative site. Thus during laparoscopic task performance the surgeon is confronted with a mapping problem and cannot look at his hands during the manipulations.

1.2 Laparoscopic surgery task performance

1.2.1 Performance shaping factors in laparoscopic surgery

Complex tasks require the careful identification of all factors which can alter how subjects perform their jobs. Performance shaping factors can be divided into external and internal factors. Laparoscopic surgeons' ability to provide high-quality care can be adversely affected by many factors. Figure 1 shows some extrinsic and intrinsic factors that can directly influence laparoscopic task performance. The intrinsic factors are those related to the operating team themselves such as experience, sleep status and team work coordination. The extrinsic factors were divided into two main categories: organisational factors, factors related to the operating room and factors related to the task. The operating room factors were further divided into operating room environment factors (such temperature, humidity and noise) and operating room lay out factors (eg. position of the operating team to each other, patient and equipments).

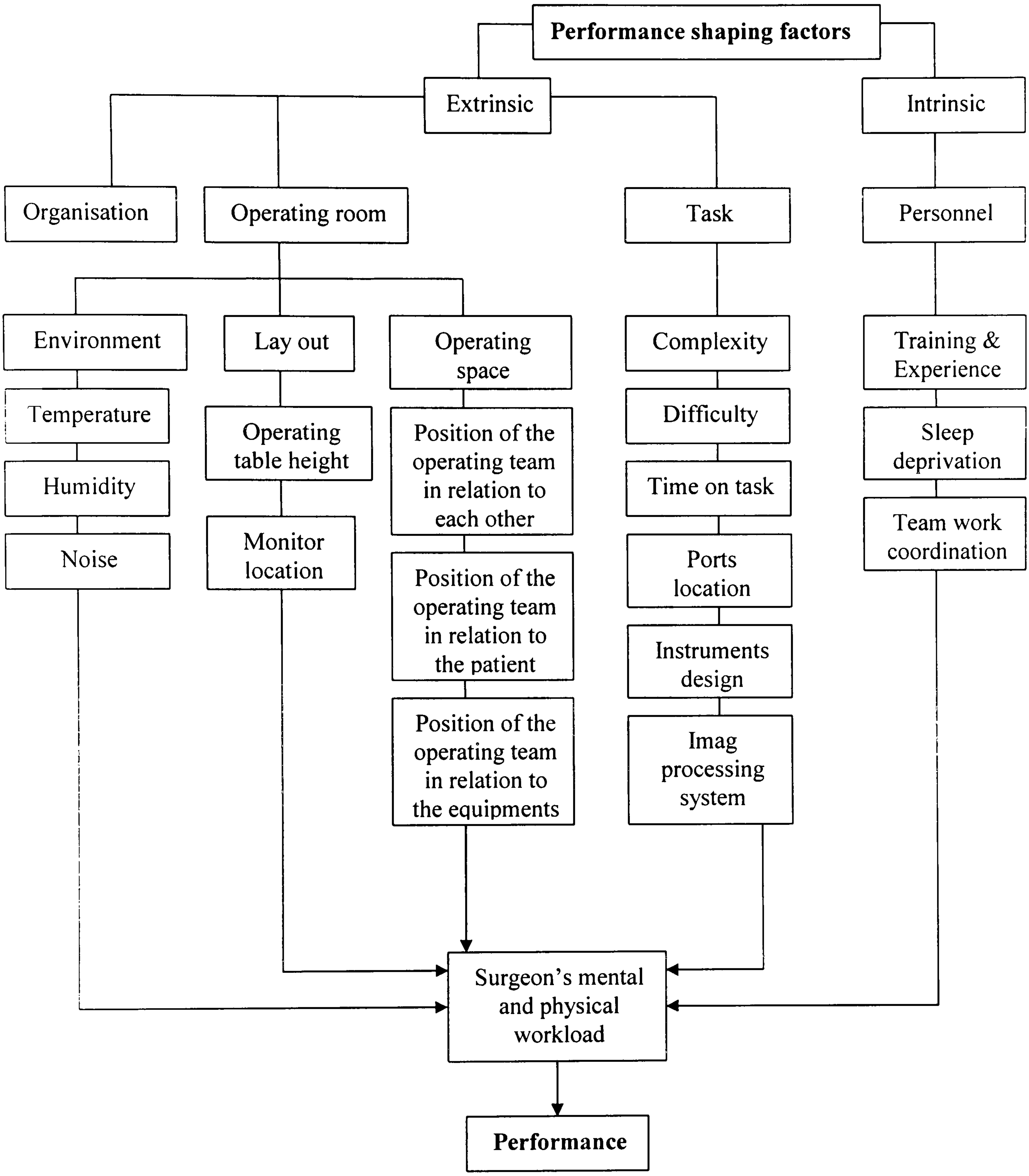

Figure 1: Laparoscopic ask performance shaping factors

1.2.1.1 Intrinsic factors

1.2.1.1.1 Sleep deprivation

Sleep is divided into periods of Rapid Eye Movement (REM) and Non-Rapid Eye Movement (NREM). Normal night sleep commences with NREM, which is divided into four stages: stage four, also known as Slow Wave Sleep, is the deepest form of sleep; one and two are lighter and closer to arousal. Adults typically need between 6 and 10 hours of sleep per 24-hour period (Pilcher & Huffcutt 1996).

Altered sleep schedules can lead to either partial or total sleep deprivation. Total sleep deprivation, where the individual gets no sleep, is more likely to occur in acute situations (eg, studying all night). Partial sleep deprivation refers to a night of reduced or interrupted sleep, which might be due to sleep disorders, medical conditions, medications or work schedules. Recurrent episodes of partial sleep deprivation, therefore, are most likely to be of relevance to surgeons.

Sleep deprivation can affect clinical performance and may be an important factor in patient safety. Sustained wakefulness of 28 hours has been found to result in a decline in cognitive psychomotor performance equivalent to that observed at a blood alcohol concentration of 0.10%, which is above the legal limit for driving an automobile (Dawson & Reid 1997).

Seven studies in the literature reported the effect of sleep deprivation on laparoscopic task performance (table 1). All the reported series used simulated laparoscopic tasks out of which five used MIST virtual reality simulator. Two studies reported that sleep deprivation has no effect on laparoscopic skills acquisition, four concluded that sleep deprivation adversely affect surgeons performance, whereas one study disclosed that sleep deprivation had no impact on surgeons performance. However, these studies have some limitations: (1) All the studies were carried out on simulated laparoscopic tasks; (2) There is no standardised definition of a sleep deprivation in these studies; (3) The quality of sleep was not included in the studies; (4) Other performing shaping factors, such as room temperature, were not mentioned in the studies (5) No study included the influence of sleep deprivation on the subjects' mental workload to know how subjects cope with this performance shaping factor, because subjects might adapt the strategy of performing the task with low mental workload and therefore they decreased their performance; (6) The duration of task was not mentioned in the reviewed studies. As the effect of sleep deprivation on subject's performance might not be seen when performing a laparoscopic task over a short period of time, it is important to include the duration of the performed task. Although sleep deprivation might not influence the task performance (as shown by one study) or skill acquisition (as shown by two studies) it can affect subject's mood and hence it might affect team work coordination. Therefore further research is need on the affect of sleep deprivation on laparoscopic task performance, errors rate, mood and team work coordination.

Table 1: The effect of sleep deprivation on laparoscopic task performance

Study	Subjects	Definition of sleep deprivation	Task	Measures	Results
(DeMaria et al., 2005)	17 surgical residents	Night on call	MIST-VR	Economy of movement, time and number of errors	Sleep deprivation does not impair laparoscopic skills acquisition
(Grantcharov et al., 2001)	14 surgical trainees	Less than 3 hours	MIST-VR	Error of motion, time of motion and economy of motion	Impaired speed and accuracy of movement after a night on call
(Jensen et al., 2004)	40 surgical residents	Ranged from 0-8 hours	Pegboard, cup drop, rope pass, pattern cutting, clip application and loop application	Task execution time and number of errors (penalty score and total score)	Sleep deprivation does not impaired laparoscopic skill acquisition
(Kocher et al., 2006)	5 post-fellowship surgeons	3-5 hours	MIST-VR	Task execution time, total diathermy time, number of errors, injury time	Sleep deprivation adversely affect surgeons performance
(Eastridge et al., 2003)	35 Surgical residents	0-3.5 hours	MIST-VR	Task execution time, number of errors, economy of motion	Sleep deprivation adversely affect surgeons performance

Table (1) continue

Study	Subjects	Definition of sleep deprivation	Task	Measures	Results
(Taffinder et al., 1998b)	6 surgical trainees	Awake all night	MIST-VR	ICSAD: task execution time and number of errors	Sleep deprivation adversely affect surgeons dexterity
(Uchal et al., 2005)	64 surgeons	1.5 hours (sleep deprived) against 6.5 hours (non sleep deprived)	Suturing perforated ulcer in a foam hollow stomach	Accuracy error, tissue damage, leak rates, goal directed actions, non-goal directed actions and operating time	Sleep deprivation had no impact on surgeons performance

1.2.1.1.2 Surgeon's experience

There is no doubt about the effect of experience on surgical performance and outcome. However, to our knowledge there is no reported study on the effect of surgeon's experience and training on mental workload during laparoscopic task performance. Few studies are reported in the literature on the relation between surgeon's experience and physical workload. Uhrich et al., studied the impact of surgical experience on fatigue during laparoscopic task performance by comparing the electromyogram (EMG) and subjective discomfort questionnaire of attending and resident surgeons (Uhrich et al., 2002). In the Uhrich et al. series, four attending and four resident surgeons repeated a series of four tasks (point to point, needle pass, cylinder/Peg Board, and needle drive/knot tying) with a View site projection screen and a standard operating room monitor. Each subject performed each task 10 times. Electromyography (EMG) activity and muscular discomfort scores were recorded for 30 seconds during the first and the 10th run. The attending surgeons showed significantly lower activity than did the residents surgeons for the middle trapezius, sternocleidomastoid, and hamstring muscles. The results from the subjective discomfort questionnaire scores showed a significant difference between the two levels of experience in both lower erector spinae and the left hamstring. The resident surgeons showed significantly greater discomfort than did the attending surgeons. Uhrich et al., did not include the results of the performance in their study. The decrease in the muscle activity might be because the attending (expert) surgeons completed the tasks with low level of performance. Due to this and the small sample size it is difficult to conclude from their study that experience decreased the muscle activity during laparoscopic task performance.

Emam et al., studied the effect of experience on the performance and motion pattern of the dominant upper limb during endoscopic intracorporeal knot tying (Emam et al., 2000a). They enrolled two groups of 5 surgeons (expert consultants and higher surgical trainees). The surgeons tied 360 surgeon's knots inside an endoscopic trainer in a random sequence. Motion analysis at the elbow and shoulder joints of the dominant upper limb was carried out using three-dimensional kinemetrix system. Performance was measured using execution time, knot quality score. The study showed a significant difference in task performance, angular velocity and range of movement at the shoulder joint of the dominant upper limb. The authors concluded that better task performance by expert surgeons was associated with controlled rapid manipulations and a wider range of movement at the shoulder joint of the dominant upper limb. The sample size and the use of only one laparoscopic task in the study make it difficult to apply the results to other laparoscopic tasks. As the authors did not use electromyography or a subjective rating of workload in the study, we can not relate between surgeons level of experience and their workload. Therefore further studies are needed to investigate the effect of experience on the pattern of dominant upper lime movement and muscle activity during different laparoscopic tasks.

1.2.1.1.3 Surgeon's training

The introduction of laparoscopic surgery in clinical practice without matched training programme has resulted in high complication rate, especially with novice surgeons. It has been consistently reported that surgical complications occur most frequently during the first 10 procedures that the laparoscopic trainee performs (Peters et al., 1991; Wherry et al., 1994).

Teaching junior residents basic laparoscopic skills in the operating room can be frustrating for both the attending and resident surgeons, as well as time consuming and inefficient (Anastakis et al., 1999). The initial part of the learning curve has a high complication rate which is no longer accepted to patients. On the other hand; training surgeons outside of the operating room to perform laparoscopic surgery may decrease operative complications (Martin et al., 1998), enhance efficiency (Reznick 1993), and reduce long-term cost. The importance of adequate practice before attempting procedures on live patients has been highlighted by the rates of serious complications (Coleman et al., 1994). Surgical success is multifactorial requiring not only good technical skill, but also sound judgment and knowledge (Scott et al., 2000). Both didactic and hands-on skills training are integral parts of any curriculum used to establish a link between performance on an ex-vivo surgical training system and performance in the operating room. However; previous efforts to train surgical residents in the skills laboratory have been devoid of didactic sessions to improve cognitive knowledge (Derossis et al., 1998; Reznick et al., 1997; Rosser, Jr. et al., 1998).

Imaging and mechanical constraints in laparoscopic surgery impose certain challenges for skills acquisition (Melvin et al., 1996; Wolfe et al., 1993). Performing laparoscopic surgery requires the use of 2-dimensional information to produce 3-dimensional movements, as well as precise motor control for manipulating laparoscopic tools. Long instruments through access ports diminish tactile feedback and can be awkward to use. Video-eye-hand coordination must be improved to correctly position instruments in the operative field. The added visio motor demands make it more demanding and complex than traditional open surgery. Difficulties are not however constrained to motor issues. Problems also arise from perceptual constraints involved in laparoscopic surgery. The reduction in tactile information leads to degraded proprioceptive feedback versus that of open surgery. Perceived image inversion "fulcrum effect" also effects perceptual task performance. Furthermore, the transfer and translation of the 2-D image into a 3-D movement must occur in spite of loss of binocular information. The altered binocular information consequently leads to problems in hand-eye coordination and cognitive mapping (Crothers et al., 1999). It is also possible that older surgeons, with more experience in the "open" domain, have established cognitive networks, which may interfere with adaptation to the laparoscopic environment (Risucci et al., 2001).

Several options exist for teaching surgical skill outside the operating room. These include courses with practices in animal models and training with other certified laparoscopic surgeons. One of the models utilised for training in laparoscopy is the surgical simulator, which allows the operator to enhance his/her motor skills in a safe and controlled environment. Cadavers offer a high degree of fidelity to the living patient and a non pressured learning atmosphere. But cadavers are costly, of limited availability, and have noncompliant tissue that may be difficult to use for operations. Live animal models may also be useful. But animals differ in anatomy from humans, can be costly, require appropriate facilities and personnel, and raise ethical concerns. Skill transfer from the laboratory to clinical practice is crucial for medical education. It is necessary to determine how specific the training context must be in order for benefits in the clinical setting to be seen. Seymour et al., studied the effect of virtual reality training on the surgeon's clinical performance (Seymour et al., 2002). They studied the psychomotor abilities of 16 surgical residents before randomising them to either virtual reality training group (MIST virtual reality simulator) or control group. The virtual reality trained group were trained until expert criterion levels established by experienced laparoscopic surgeons were achieved. All the residents performed laparoscopic cholecystectomy supervised by an investigator surgeon. The supervising surgeons were blind to the subject's training status. The dissection of gallbladder from the liver was videotaped for each subject for later analysis. Before the procedure all the subjects viewed a video tape demonstrating optimal performance of dissection of gallbladder from the liver bed. The video defined specific deviations from optimal performance that would be considered errors. After viewing the video the residents were asked to answer 8 multiple choice questions that tested the recognition of these errors. The authors reported that gallbladder dissection was 29% faster for the virtual reality trained residents. The control residents (non virtual reality trained residents) were 9 times more likely to transiently fail to make progress and 5 times more likely to injure the gallbladder or burn non-targeted tissue. Errors were 6 times less likely to occur in the virtual reality trained residents.

Tang et al., suggested that training in laparoscopic surgery should be individualised as innate ability varies among trainees (Tang et al., 2005). The authors used observational human reliability analysis to analyse the errors rate during 60 simulated laparoscopic cholecystectomies on porcine gallbladder performed by 60 surgical trainees. The study showed a wide variation in the number of errors between the 60 trainees. Gallagher et al., performed a review on the factors which can effect the successful integration of virtual reality training into a surgical training programme (Gallagher et al., 2005). They reported that master surgeons occupy less attentional capacity than the novices for basic psychomotor, spatial, and decision making process. In addition they reported that the automation process is determined by the level of surgeons' fundamental mental abilities and the experience they have gained. Therefore, the rate of automaticity during skills acquisition varies widely among surgeons based on their fundamental abilities such as visio spatial, perceptual, and psychomotor abilities.

Whilst the effect of innate abilities on skills acquisition and performance has been studied in open and laparoscopic surgery, the potential impact of innate abilities on surgeon's mental and physical workload has not been explored.

1.2.1.1.4 Team work coordination

The benefits of teamwork in improving the quality of patient care have been emphasised in a number of studies (Blythe et al., 2001; Thornton & White 1999). Teamwork can be defined as a small number of people who are committed to a relevant shared purpose, have common performance goals and a common approach to the work. Operating room teamwork means combining team members' complementary and overlapping skills, time and economic resources (Crowell 2000; Rudisill et al., 1994), and having mutual understanding while taking care of patients undergoing surgery (Kleinbeck 2000; McNamara 1995). Teams are also likely to provide support to less experienced staff and so reduce stress (Firth-Cozens & Moss 1998). Teamwork is emphasised in the operating room because of the need to bring together the diverse skills of different occupational groups. Their particular responsibilities within a highly technical and pressurised environment need to be identified in order to work together pleasantly and ensure the smooth implementation of high-quality intraoperative care. Improved teamwork can be assumed to decrease the probability of errors and to increase the collective responsibility for error prevention. However; surgical education has tended to emphasise the teaching of clinical skills at the expense of teamwork skills (Crowe et al., 2000). In aviation, even in fatigue conditions, team members were able to correct or compensate errors if they had worked together for a long time (Sexton et al., 2000). Therefore, the high turnover in the operating room teams might be potential sources of errors.

Sexton et. al., studied the error, stress and team work in medicine and aviation using cross sectional surveys (Sexton et al., 2000). Despite the multiple stresses that surgeons face, they were more likely to deny the effects of stress on their performance than pilots and anaesthetist. The different perspectives on teamwork among medical staff were shown by the responses to the item "Rate the quality of teamwork and communication or cooperation with consultant surgeons". Sixty four percent of surgical consultants and 73% of residents rated the teamwork they experienced with other consultant surgeons as high, whereas; 9% and 7% reported low levels respectively. Ten percent anaesthesia residents, 26% anaesthesia nurses, and 28% surgical nurses rated interactions with consultant surgeons at high level compared to 43%, and 48%, 39% reported low levels respectively. At the aggregate level, 62% of surgical staff rated teamwork with anaesthesia staff highly, and 41% of anaesthesia staff rated teamwork with surgical staff highly. In other words, surgery generally reports good teamwork with anaesthesia, but anaesthesia staff does not necessarily hold a reciprocal perception. Unfortunately there is no reported study on the relation between team work coordination and laparoscopic task performance.

1.2.1.2 Extrinsic factors

1.2.1.2.1 Operating room layout

Posture is as important for the performance of tasks as it is for promoting health and minimizing stress and discomfort during task performance. Poor posture can cause static muscle loading and fatigue (Corlett & Bishop 1976) as well as impaired psychomotor task performance (Bhatnager et al., 1985).

Ergonomists are now well aware of the influence of workplace layout on the ability to perform tasks in industry and surgery. The concept of a good 'working posture' becomes fundamental to the ergonomic design and layout of workplaces. However; no clear definition of 'posture' can be found in the ergonomics literature. Posture arises from the functional demands of vision, reach, manipulation, strength and endurance, and is constrained by the geometric relationship between the person's own anthropometry and the layout of the workplace (Haslegrave 1994). Congleton et al., defined the natural body posture as the posture found in weightlessness, where the muscle, tendon, and ligament systems acting over the joints are in total balance (Congleton et al., 1985).

There are limited sources on postural analysis among surgeons in the literature. Open surgical operations are attended by more surgeons' head-bent and back-bent posture, whereas during laparoscopic procedures surgeons more often hold a head-straight and back-straight posture (Berguer et al., 1997). This static posture of the back may increase surgeon fatigue over time. The ergonomically ideal position for the laparoscopic surgeon was preceded from anatomic and physiologic considerations (Matern & Waller 1999). In this position, the arm is slightly abducted, retroverted, and rotated inward at shoulder level. The elbow is bent at about 90-120°, and the hand grasps the instrument in the basic position. In this series the authors did not included the position of the remaining parts of the body.

Laparoscopic operating team posture and performance can be affected by the operating table height, image display system (monitor) location, ports locations and instruments design. Ports locations and instruments design will be discussed in the task related factors section (1.2.1.2.3.2). The location of the monitor largely determines the body posture of the surgical team in laparoscopic surgery (table 2). This is because it affects the orientation of the eyes and hence the head posture which in turn determines neck and trunk position and affects positioning of other body parts. Ergonomic studies show that the posture during tasks using video display terminals is optimum when there is no torsion of the back and neck and the head slightly flexed at an angle of 15-45° to the horizontal. This posture prevents fatigue and musculoskeletal disorders (Burgess-Limerick et al., 2000; de Wall et al., 1991; Jaschinski et al., 1998; Turville et al., 1998).

Table 2: Reported series on the effect of monitor location on surgeon's posture and performance in laparoscopic surgery

Study	**Subjects and tasks**	**Monitor location**	**Results**
(Veelen et al., 2002)	Twelve surgeons performed real laparoscopic cholecystectomies	At eye level and at operating field level	Assistant had more neutral head flexion and neck torsion with monitor at operating field level. No difference was seen in the posture of the operator. The operator and assistant preferred the lower monitor set up.
(Uhrich et al., 2002)	Four attending and 4 resident surgeons.	In front at eye level and in front at operating field.	Mean RMS for upper trapezius was higher with the lower monitor position. Mean RMS for sternocleidomastoid was higher with eye level position. No difference in subjective score.

Table 2 continue

Study	Subjects and tasks	Monitor location	Results
(Hanna et al., 1998c)	Ten laparoscopic surgeons performed simulated intracorporeal knot tying.	Monitor was placed at subject's eye level and at operating field in each of the following directions: in front, to the left, and to the right of the subject.	Execution time was shorter and performance quality score was higher with the frontal view direction compared to the left or right viewing direction. Execution time was shorter and performance quality score was higher with hand level compared to the eye level location.
(Erfanian et al., 2003)	Surgeons with different laparoscopic experience performed real laparoscopic appendicectomy	In front at eye level and in front at operating field	Placing the laparoscopic image at the operating field decreased operating time by 10% compared to eye level position.

Table 2 continue

(Omar et al., 2005)	Twenty medical students performed laparoscopic touching task with unilateral and bilateral manual coordination, and 3 laparoscope misalignment.	In front at eye level and in front at operating field.	Lower monitor position reduced task time and errors; the reduction in time and errors is more appreciable as task complexity increases.
(Matern et al., 2005)	Eighteen subjects without surgical experience performed simulated laparoscopic task.	Frontal at eye level, frontal at operating field, and 45 to the right side at eye level	EMG activity was lower with frontal at eye level. Task performance was better with frontal at operating field. Subjects preferred two monitors one frontal at eye level and one frontal at operating field.
(Vereczkei et al., 2004)	Two experienced surgeons performed 20 real laparoscopic cholecystectomies.	At the patient's head in the centre and at the left side of the patient facing the surgeon.	When the monitor was facing the surgeon, head and trunk posture were closure to comfort posture.

The height of the operating table relative to a subject performing laparoscopic procedure effects upper extremity effort and the potential for muscular fatigue. The reported studies on the operating table height in laparoscopic surgery showed that the optimal table height range for laparoscopic surgery is lower than those currently available which necessitate the redesign of these operating tables (Berquer et al., 2002; van Veelen et al., 2002). Berguer etal., investigated the optimum operating table height in laparoscopic surgery. In their series, twenty-one surgeons performed a simulated laparoscopic cutting task using a laparoscopic video system and laparoscopic instruments positioned at five instrument handle heights relative to subjects' elbow height (-20, -10, 0, +10, and +20 cm) by adjusting the height of the trainer box. Subjects rated the difficulty and discomfort experienced during each task on a visual analog scale. Skin conductance (SC) was measured in micromhos via paired surface electrodes placed near the ulnar edge of the palm of the right (cutting) hand. The mean electromyographic (EMG) signal from the right deltoid and trapezius muscles was measured. Arm orientation was measured in three dimensions using a magnetometer/accelerometer. The authors concluded that optimal table height for laparoscopic surgery should position the laparoscopic instrument handles close to the surgeons' elbow level to minimise discomfort and upper arm and shoulder muscle work (Berquer et al., 2002). Task execution time was not affected by the operating table height. Further studies are need in this area using real laparoscopic tasks or tasks more closely to the real ones to investigate the effect of operating table height on task performance.

Van Veelen et al., performed two experiments to investigate the effect of operating surface height (The level of the abdominal wall of a patient with pneumoperitoneum) on the shoulder, elbow and wrist joints position during two simulated laparoscopic tasks (van Veelen et al., 2002). In the first experiment 8 subjects with different laparoscopic experience performed a pick and place task under 6 different table height (0.5, 0.6, 0.7, 0.8, 0.9, 1.0) of the subject's elbow height with the subject in standing position. Two video cameras (one above and one in front of the subject) were used to record the position of the hand and arm. The angles of the joints excursion were rated from neutral to extreme according to predefined criteria. Subjects were asked to score the selected table height regarding their comfort/discomfort on a visual analog scale, uncomfortable 0 mm and comfortable 100 mm. In the second experiment 8 subjects were asked to hold a camera connected to a laparoscope for 15 minutes under the same table heights used in the first experiment. The electromyogram of the biceps brachii was recorded during this study. The authors reported that the optimal operating height lies between 0.7 and 0.8 of the elbow height where the joints excursions stay in the neutral position for more than 90% of manipulation time and the activity of biceps brachii stays within 15% of the maximum muscle activity. In the first experiment the authors did not mentioned the selected joints land markers and how they measured the joints angles. In the second experiment the subjects were in static (fixed) position and therefore the results of the experiment can be applied to the camera operator but not to the surgeon.

In industry it is reported that discomfort, fatigue, and awkward postures can all decrease forces exerted and undermine precise movement coordination (Liao & Drury 2000; Pan & Schleifer 1996). Both effects potentially and impact performance. Decreased performance (e.g. errors) has been directly associated with increased discomfort in video display terminal (VDT) task (Liao & Drury 2000).

There are at least three possible mechanisms for posture to affect performance (Straker et al., 1997):

- Poor posture could change the mechanical advantage of muscles requiring a suboptimal neuromuscular utilisation. This may effect either the stabilisation upon which movement is generated or the movement itself.
- Poor posture could accelerate the onset of muscular fatigue leading to a decrement in movement co-ordination.
- Poor posture could lead to discomfort which could distract the person's attention. This reduces the amount of attention which could be paid to maintain performance.

1.2.1.2.2 Operating room environment

Surgeons often perform complex tasks under unsuitable environmental and organisational conditions. The operating room environment in which surgeons work is becoming more stressful and demanding. Demands result from the rapid changes in surgical techniques and surgeon machine interface.

Noise is one of the most obvious distractions in the operating room. Noise levels as high as 80 to 85 dB have been measured in operating rooms (Hodge & Thompson 1990; Shapiro & Berland 1972). Many sources, including suction machines, monitors, alarms, and conversation between individuals, contribute to the noise level. This noise is often well over the recommended standards of 45 dB in a working environment as set by the Environmental Protection Agency and the International

Noise Council (Cabrera & Lee 2000). There can be further intermittent increases of 30 dB over the background noise levels due to equipment use, shouting, and dropped equipment (Hodge & Thompson 1990).

Shapiro et al., reported that noise levels in the operating room can be high enough to cause deterioration in the ability to communicate, to increase stress levels, and to affect complex motor skills (Shapiro & Berland 1972). Cabrera and Lee suggested that improving the noise levels in the operating room will reduce fatigue, psychological and physiological effects in the surgeon which consequently promote accuracy (Cabrera & Lee 2000). Moorthy et al., studied the effect of adverse environmental conditions on laparoscopic performance (Moorthy et al., 2003a). Participants performed a laparoscopic transfer task under five conditions: high mental workload condition, operating theatre background noise at 80 to 85 dB, time stressor condition, all three conditions combined and quiet conditions. All three stressors led to impaired dexterity and an increase in the incidence of errors. In another study Moorthy et al., demonstrated that noise, when present as an independent stressor, had a significant influence on the knowledge based errors but not the skill based errors (Moorthy et al., 2003a). However; the effect of noise on operative performance depends on the complexity of the task to be performed and the skill level of the individual. Inexperienced surgeons who are still in the phase of association of learning of psychomotor skills possibly would be affected by noise to a higher degree than surgeons in the phase of automation (Reznick 1993). On the other hand experienced surgeons became acclimatised to noise while performing a surgical task and could thus effectively block out the presence of these auditory stimuli (Moorthy et al., 2004).

1.2.1.2.3 Task related factors

1.2.1.2.3.1 Image processing system

Visual perception is the main sensorial impression from the operating field in laparoscopic surgery (Schurr et al., 1999). Hence, the surgical performance and clinical outcome depends on the imaging system. Laparoscopic imaging technology has remarkably improved in recent years (Berci & Paz-Partlow 1988). This is mainly related to the increase in the application of laparoscopic surgery (Boppart et al., 1999). However, image processing is still considered to be in it is early stages. Misinterpretation of the image displayed on the monitor leads to increase in the surgical errors and complications among laparoscopic procedures (Holden et al., 1997). This in turn, has a negative feedback effect on the benefits of laparoscopic surgery.

As laparoscopic surgery has become the standard treatment for several surgical diseases (Boppart et al., 1999), limitations of imaging in this surgery should be minimised in order to utilize its potential benefits. This section will discus the limitations of imaging in laparoscopic surgery, and some of technical solutions to overcome these problems. Five aspects of the sense of vision can be identified as a model for laparoscopic imaging tools: (1) Direction of the line of sight; (2) Maintenance of clear vision; (3) Spatial vision; (4) Differentiated visual field and panoramic view; (5) High resolution (Schurr et al., 1996).

1.2.1.2.3.1.1 Direction of line of sight

In laparoscopic surgery there is dissociation between the direction of the surgeon's line of sight and his hands, i.e. surgeon's motor function is separated from his/her sensorial function. This dissociation becomes clearer in case of an inexperienced camera assistant, due to misunderstanding between the surgeon and the camera assistant. Therefore, the surgeon loses his visual autonomy.

To overcome this problem, this dissociation should be reduced to approximate the surgeon's line of sight to his hands. By putting the monitor in front of the surgeon the surgeon's line of sight could be brought back toward his hands. However, as the surgeon still depends on the camera assistant to perform his operative manipulations, the dissociation between the surgeon's vision and hands, is not completely eliminated. Some new operative imaging systems provided endoscope guidance tools controlled by the surgeon. Different robotic assistant devices are currently available on the market, but their application in laparoscopic surgery is still under practical and scientific investigation. This type of advanced system allows the surgeon to direct the laparoscopic line of sight by himself using an endoscope guiding system. The finger of the surgeon guides the endoscope via a special joystick in all four axes (Schurr et al., 1996). This type of technique can avoid the dissociation between the hands of the surgeon and the line of sight of the telescope, but not the surgeon's line of sight and his hands. A head- mounted display is another system, which can help to overcome this dissociation. In head- mounted display systems, the image can be displayed on glasses worn by the surgeon. Psychomotor skills studies showed that the best task efficiency during laparoscopic surgery is obtained when the surgeon looks down at the image in close proximity to his hands (Hanna et al., 1998c). This principle was the basis for the development of the Dundee Image Projection System that projects the image on a sterile screen near the operative field. Also, a new advanced technical system, which called as suspended imaging system is still under research by Research Laboratories (CRL, Hayes, Middlesex, United Kingdom) and Department of Surgery and Psychology at the University of Dundee (Cuschieri 1996). The suspended image system projects the image into the space near the operative field. The size of this system and its integration into the operating room layout requires further research and development.

1.2.1.2.3.1.2 Maintenance of clear vision

In laparoscopic surgery, visual clarity is affected by several factors, such as blood; steam created by diathermy; and fog due to the difference in the intracorporeal and the scope temperature. This can be dangerous as laparoscopic surgery is an image-guided surgery.

Currently, the most used method for cleaning of the scope is by external warming devices. This is done either by soaking the tip of the scope in hot water or by using special warming devices. However, after introducing the cleaned scope into the body, steam, fog, and may be blood will be smeared on the lens. This makes another cleaning and warming process necessary, leading to an interruption to flow of surgery. Some surgeons prefer to clean the scope by rubbing it against the liver, but still this process leads to lose of the field, which needs readjustment of the view. Both these methods are time consuming especially during emergency situations.

Certain principles were determined to maintain clear vision in laparoscopic surgery, which summarised in table 1 (Bessell et al., 1996).

Table 3: Principles of clear vision in laparoscopic surgery

1. Optic front lens warmed to≥37°;
2. Insufflation gas warmed to 37°;
3. Insufflation gas humidified at 50%-80%;
4. Insufflation directly over front lens;
5. Facility to rinse and dry front lens;
6. Constant flow of insufflation gas and
7. Facility to exsufflate smoke during electrocautry

1.2.1.2.3.1.3 Spatial vision

Laparoscopic surgery places a great demand on surgeons as visual feedback necessary to control movements in three-dimensional (3D) space is currently displayed on a two-dimensional (2D) monitor. Several studies have been carried out to improve the image in laparoscopic surgery and make it closer to the real one provided by the naked eye during open surgery.

Three dimensional video laparoscopic systems provide a binocular spatial perception of the operating site and a more distinctive view on the intracorporeal structures (Pichler et al., 1996). However, studies made on the available 3-D systems have not showed any material benefit over the applied two-dimensional systems (table 4). In addition to that, the error rates; first time accuracy; and task performance are not improved by the available 3-D systems (Hanna et al., 1998b; Hanna & Cuschieri 2000; Holden et al., 1997).

Table 4: Studies compared two dimensional (2D) with three dimensional (3D, stereoscopic) laparoscopic imaging systems

Study	Subjects	Type of study	Measures	Results
(Chan et al., 1997)	Thirty-two surgeons (11 experienced in laparoscopic surgery)	Place 10 beads on a suture using a straight needle	a) Assessment by surgeon. b) Time	a) 30/32 depth perception improved; 15/32 handling ability not improved; 3/32 dizziness or eye strain. b) No difference in completion time
(Crosthwaite et al., 1995a)	Two surgeons, 1 technician	Knot tying task	Time, knot strength	No difference in time or knot strength between 2D and 3D
(Dion & Gaillard 1997)	a) Ten subjects b) Nine subjects	a) determine relative position of sticks b) put rings around sticks	a) time and error rate b) time	No difference for time, decrease errors with 3D b) faster with 3D, most subjects preferred 3D, some complains about eyewear and dizziness

Table 4 continue

Study	**Subjects**	**Type of study**	**Measures**	**Results**
(Hanna et al., 1998b)	Twenty surgical residents	Randomised controlled trail for clinical laparoscopic cholecystectomy	a) Time and error rate b) Assessment by surgeon	No difference for time and error rate 3D: better depth perception, worse image quality and more adverse effects
(Jones et al., 1996)	Ten students, 10 non laparoscopic residents, 10 laparoscopic surgeons	Five different tasks in video training module	a) Time b) Assessment by subjects	No significant difference in time 18/30 more control and accuracy with 3D, students preferred 2D, surgeons no preference
(Mueller et al., 1999)	Twenty untrained, 10 experienced in laparoscopic surgery	Four different tasks in pelvitrainer (grasping and displacing objects, handling elastic bands)	Time and error rate	No consistent effect for both variables, more complaints about loss of concentration, headaches for 3D, some time need to adapt to 3D

Table 4 continue

Study	Subjects	Type of study	Measures	Results
(Taffinder et al., 1999)	Twelve experienced surgeons, 16 novices	Grasping and cutting (novices), suturing (experienced)	Time, instrument movement efficacy	Detrimental effect reduced by 50% with 3D
(Wenzl et al., 1994)	Eleven surgeons	Gynaecologic laparoscopy	Assessment by surgeon	Surgeons got used to 3D in 5 minutes, good perception of depth, manipulation of instrument easy

To date, 3- Dimension impressions given by human vision has not been perfectly achieved by the current systems. The 3-D impressions provided by human vision are generated by two different principles: stereoscopic inspection of the object and secondary signs of spatial relation. The stereoscopic inspection is responsible for 3-D impressions of targets in the typical field of human action, whereas the secondary signs of spatial relations are beneficial in estimation of the relations of objects in 3-D space (Holden et al., 1997; Schurr et al., 1996). So these two factors should be taken in consideration for the development of laparoscopic systems.

With stereoscopic video technologies it is possible to display visual spatial information on a single video monitor (Pichler et al., 1996). Currently, the principles of stereoscopy have been transferred to endoscopy, either by using a scope provided with two lenses, or with the use of optical shutter technology (LCD glasses worn by the surgeon). However, the existing stereoscopic scopes have many disadvantages. Besides causing headaches, nausea, and vertigo, optical shutter technology leads to a substantial loss of incident light. Therefore, the image is distinctly darker and the colour is degraded (Holden et al., 1997). All current 3-D systems have fixed horizontal disparity, and have a limited operational distance such that a 3-D effect is only obtained when the optic is at a given distance range from the target (few cm) (Cuschieri 1996). Further results of 3-D video evaluation show that two-channelled optics can provide stronger spatial impression s, but they lack the free rotation-ability (Schurr et al., 1996).

Suspended imaging technology provides 3-D impressions without effecting the resolution and brightness of the image displayed (Cuschieri 1996). In this type of technique we can get 3-D image without using any screens (Figures 2 and 3). However, the large area required for the equipment of this technique, makes the current technology inapplicable to clinical practice. This technique requires a completely dark room for the suspended image to be displayed, which may cause problems for the scrape nurse, anaesthesia team, or other theatre team members. Whereas the existing monitor display systems provide an image to all the surgical team, the suspended imaging technique provides the 3-D image only to the surgeon. Therefore, the outgoing research should take in consideration the way by which the suspended image delivered to the other personnel of the surgical team, so they become involved in the operation step by step.

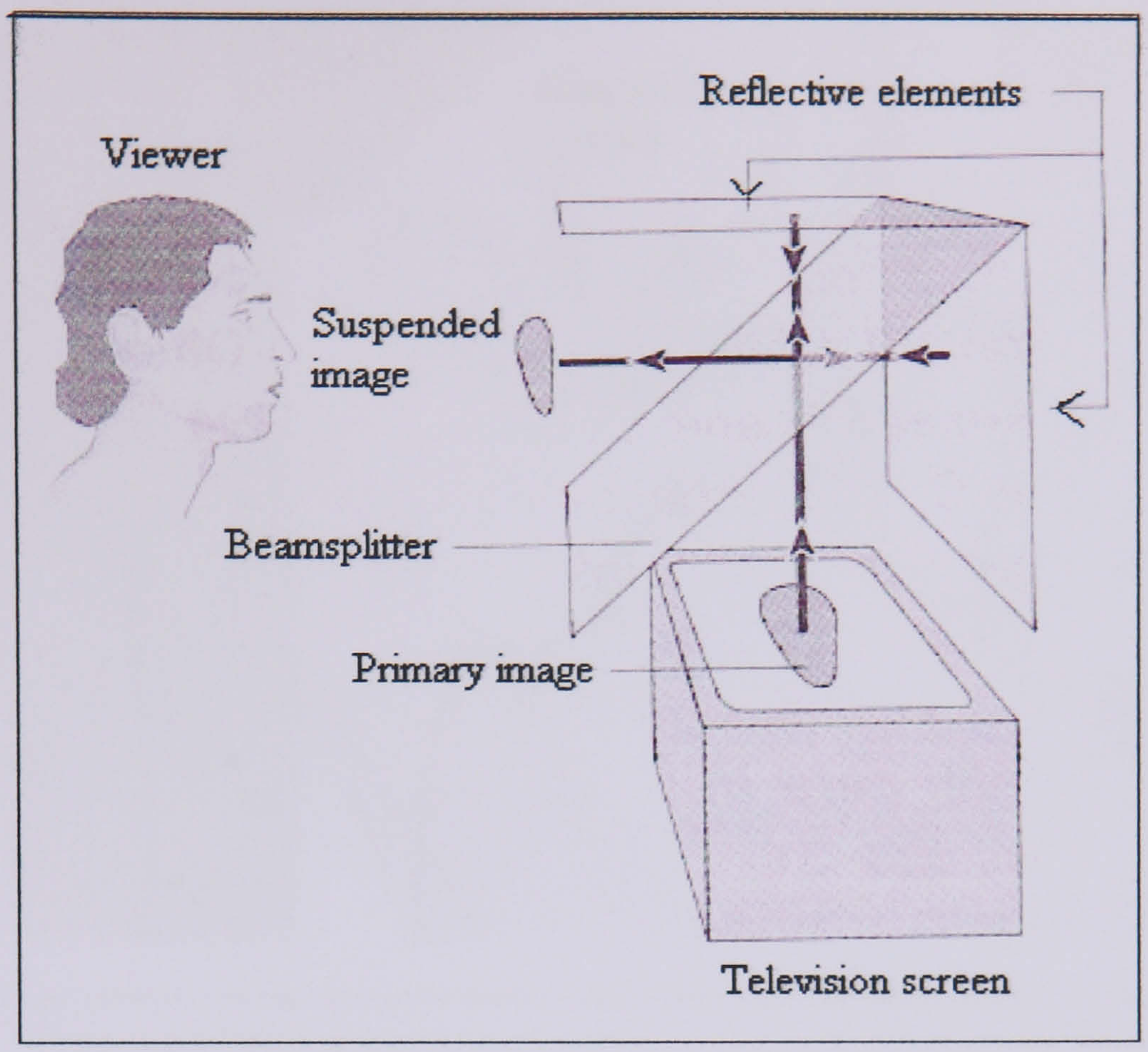

Figure 2: Basic principle underlying the suspended image system

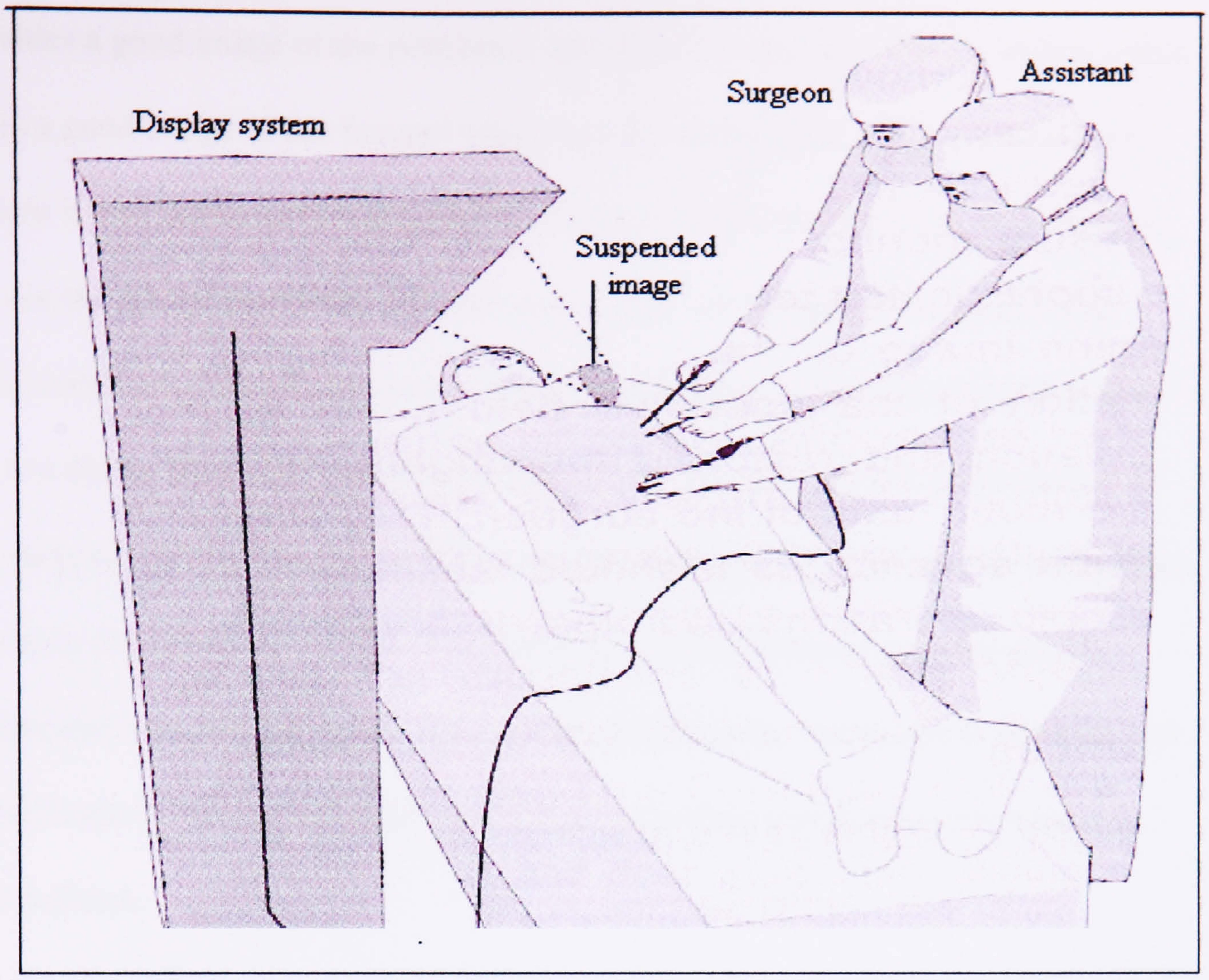

Figure 3: Suspended image system configuration for laparoscopic surgery

Due to the coaxial alignment of the lens system and illumination fibres in current endoscopes, conventional endoscopes produce no shadow which is known to be a strong depth cue. Several studies have been carried out to overcome this problem, either by using a special endoscope provided with an illumination cannula (Schurr et al., 1996), or by inserting the light and the scope from different ports (Hanna et al., 2002; Mishra et al., 2004).

1.2.1.2.3.1.4 Panoramic view and differentiation of the visual field

Human retina contains colour-sensitive cones and brightness-sensitive rods. The density of the rods is more toward the central of the retina (fovea centralis), whereas the rods are concentrated in the peripheral of the retina. Therefore, fovea centralis is the area of maximal visual acuity. On the other hand, the peripheral part of the retina provides a good image of the peripheral part of the visual field. Hence human vision gives a good image of the focused object and the lateral parts of the focused scene. Patient with a bitemporal scotoma (cerebral lesion affecting the optic chiasma) can not see the lateral part of the focused scene. This can be applied to the existing endoscopes (endoscopic scotoma), where the peripheral parts of the operative field are not displayed on the monitor and, because of that, they are not under control of the surgeon. A 135° panorama endoscope has been developed to provide wider field of vision (Schurr et al., 1996). It is important to keep instruments under direct endoscopic vision. This can be achieved by operating the endoscope to have the task in the centre of the optical field. Endoscopes providing panoramic view minimise this problem.

1.2.1.2.3.1.5 High image resolution

Resolution and colour fidelity are important considerations in minimal access surgery and endoscopy, and the optical performance of a video endoscopic system can be characterised by it is resolution, brightness and colour performance (Classen et al., 1987).

Image resolution has improved after the development of charged-coupled device (CCD) sensors (Schurr et al., 1999). These sensors are fitted to the camera, and they are electronic systems, which change the real image (photons) into electronic images that can be displayed on a screen. According to the number of these sensors (chips), cameras are classified into: single chip cameras (mono CCD), three chips cameras (tri CCD). Unfortunately, these sensors are not capable of analysing colours. Therefore, a prism or colour filters are needed. Thus the image is displayed using the three primary colours (red, green, and blue); known as RGB system. There are several designs of CCD cameras; one design uses a single monochrome CCD chip with alternating red, green, and blue illumination. By this design the space requirement is reduced and the high-resolution monochrome CCD chip technology is established (Boppart et al., 1999).

The visual acuity and resolution of the human sense of vision is not totally achieved with the current endoscopic image techniques (Cuschieri 1996; Schurr et al., 1996). Thus, there is a degradation of task performance with the use of electronic imaging of 52 per cent, with respect to direct vision (Crosthwaite et al., 1995b). It was found that there is a tendency for both endoscopically inexperienced and experienced surgeons to benefit from the use of a system with improved resolution (van Bergen et al., 2000). With the standard cathode ray tube (CRT) monitor display, the image quality (resolution, hue, luminescence) is determined by the optic, resolution of the CCD camera, and resolution and refresh rates of the television monitor (Cuschieri 1996).

The definition of a camera (chip, or sensor) may be expressed in the number of pixels, and is given by the number of points making up the image. As the number of the pixels increase the definition of the image becomes better. Charged-Coupled Device (CCD) resolution of the currently used one-chip cameras ranges between 400 000 and 440 000 pixels, whereas three-chip cameras resolution is 450 000 pixels (Schurr et al., 1996). The screen horizontal resolution should at least match, if not exceed that of the camera system (Paz-Partlow & Berci 1996). Majority of monitors used in laparoscopic surgery having a line resolution of 600-800 lines. Therefore, the improved resolution delivered by advanced 3-chip colour endocamera can not be fully realised (Cuschieri 1996).

Recently, high-definition television (HDTV) video systems have been applied to the surgical field (van Bergen et al., 2000). High-definition television (HDTV) systems showed the capability of enhancing image resolution and they have a significant effect on image plasticity (Schurr et al., 1996). However, High-definition television system (HDTV) is still not applicable in clinical routine due to it is size and price. At present, laparoscopic imaging facilities resolution, can be considered premature as it is far away from the level of the human eye. Future image techniques should be closer to the human eye, and should eliminate the difference in resolution between their image and the image provided by direct vision.

1.2.1.2.3.2 Instruments design and ports location

Instruments handles form the most important physical interface for the laparoscopic surgeon. Therefore, ergonomics should play an important role during instruments' design process. Most of currently available laparoscopic instruments are developed by a non-clinical approach and only ergonomically evaluated after the product is in the market.

Recently more attention has been paid to the ergonomics of laparoscopic surgery instrumentation. Laparoscopic instruments are subjectively and objectively evaluated using different techniques such as questionnaires (Berguer 1998; van Veelen et al., 2003; van et al., 2001), EMG parameters (Berguer et al., 1999; Emam et al., 2001), performance parameters (Emam et al., 2001; van et al., 2001) and motion analysis (Emam et al., 2001).

Emam et al., studied the influence of handle design on the surgeon's upper limb movements, muscle recruitment, and fatigue during endoscopic suturing (Emam et al., 2001). Three different handles (conventional finger loop, rocker, and ball handle prototype) were studied. Ten surgeons sutured porcine enterotomies with each of the three instruments. The endpoints were performance parameters, motion analysis and muscle work, and fatigue of the surgeon's dominant upper limb; subjective scores for comfort level and maneuverability. Using ergonomic needle drivers (rocker and ball) showed a different pattern of joint movements, a reduction in muscle power exerted during laparoscopic suturing, absence of muscle fatigue, and better performance when compared to the conventional finger loop instruments.

Ahmed et al., studied the effect of the change in the angle between the handle and instrument shaft on laparoscopic suturing (Ahmed et al., 2004). They enrolled 10 surgeons with previous experience in laparoscopic surgery. The task was to close an entrotomy located on the anti-mesenteric border of a porcine small bowel segment placed in a laparoscopic trainer box. Each subject repeated the task five times under 0, 40, and 80 degrees handle-to-shaft angle. The study showed that the best quality of laparoscopic bowel suturing was obtained with a 40° handle-to-shaft angle. There was no significant difference in task execution time between the three angles conditions. As the authors concluded, the results of this study can not be generalised to other laparoscopic tasks. The handle-to-shaft angles were studied under a controlled experimental set up. Therefore, the effect of the handle-to-shaft angle on laparoscopic task performance under suboptimal working conditions (eg. different position of the surgeon in relation to the training box (i.e. in relation to the ports) needs to be explored.

Emam et al., studied the effect of intracorporeal and extracorporeal instruments length ratio on laparoscopic task performance (Emam et al., 2000b). The authors enrolled 10 surgeons in their series. Each surgeon tied 36 knots in a trainer box. The outcome parameters were knot execution time, knot quality score, and motion analysis of elbow and shoulder joints. They concluded that intracorporeal-extracorporeal instrument length ratio below 1 degraded task performance and is associated with a wider range of movement at the elbow and shoulder joints.

The position of the instrument manipulation ports in relation to each other and to the optical port influences task performance. Hanna et al. reported that, the best laparoscopic surgery task performance is obtained with equal azimuth angles on either side of the endoscope (Hanna et al., 1997c). Furthermore, a combination of 60° manipulation angle with 60° elevation improved the laparoscopic intracorporeal knot tying. Azimuth, manipulation, and elevation angles are shown in figure 3 (section 2.1.2.10) and defined in glossary section.

Optimum task performance is obtained when the optical axis of the endoscope is perpendicular to the target plane (Hanna & Cuschieri 1999) therefore, the direction of view of the endoscope (0°, 30°, 45°) has no significant effect on task performance when the optical axis subtends the same angle with the target surface (Hanna et al., 1997b). However, in practice, the oblique viewing endoscopes provide more visual information and enhance both the correct interpretation of the anatomy and the execution of advanced laparoscopic procedures.

1.2.2 Performance shaping factors and surgical errors

Reason defined error as the failure of planned actions to achieve their desired goal. This can be in two ways: The plan is adequate but the associated actions do not go as intended or the actions may go entirely as planned but the plan is inadequate to achieve its intended outcome (Reason 2005).

Surgical errors are classified as either latent or active (Reason 2005). Active errors are those committed by the surgeon in the operating room. Such events are clearly identifiable as errors at the moment they occur. Latent errors are circumstances that predispose surgeon to errors. Examples of such latent errors include sleep deprivation, inadequate training, poorly designed tools and working environment. Therefore, fatigue can contribute to the human error component of medical errors (Leape 1994).

Gold et al., reported that nurses, who worked a rotating schedule, when compared with nurses who predominantly worked day shifts, were more likely to fall a sleep at work and were nearly twice as likely to report committing a medication error (Gold et al., 1992). Smith-Coggins et al., compared cognitive and motor performance of emergency physicians and found that, as the 24 hour study period progressed, physicians were more likely to make errors during a simulated triage test and while intubating a mannequin (Smith-Coggins et al., 1994).

Adverse events should not be misunderstood as errors. Adverse events have been defined as events that unexpectedly result in death, extended hospital stay, or extended disability after discharge (Andrews et al., 1997; Gawande et al., 1999). Human errors do not necessarily result in adverse events, and not all adverse events are the result of errors. Vincent et al., reviewed 1014 randomly drawn records from two acute hospitals in the London area, 290 (29%) were from general surgery departments (Vincent et al., 2001). The total number of adverse events reported was 119(11.7%), of which 47 (39.49%) detected in surgical patients. Leape et al., analysed the adverse events in a sample of 30,195 randomly selected hospital records; they identified 1133 patients (3.7%) with disabling injuries caused by medical treatment (Leape et al., 1991). Nearly half the adverse events (48%) were associated with an operation. Adverse events during surgery were less likely to be caused by negligence (17%) than nonsurgical ones (37%). Errors in management were identified for 58%of the adverse events.

Haynes et al., have looked at the impact of fatigue in hospital personnel on adverse events (Haynes et al., 1995). They found that the risk of postoperative complications among patients undergoing surgery was not increased when the surgical resident was sleep deprived. Haynes et al., performed a retrospective study on 6,371 surgical cases and identified 351 postoperative complications (Haynes et al., 1995). The complication data were analysed using logistic regression analysis, with outcome being the presence or absence of complications. The study revealed that sleep deprivation has no significant effect on complication incidence. Ellman et al., conducted a retrospective study on the effect of sleep deprivation on postoperative complications in thoracic surgical procedures performed by surgical residents (Ellman et al., 2004). A total of 7,323 cases were examined, 229 of these cases (3%) were performed by sleep deprived residents. A resident was designated sleep deprived if the resident performed a case that started between 10 pm and 5 am, or ended a case between the hours of 11 pm and 7.30 am. The authors concluded that acute sleep deprivation in thoracic surgical residents does not affect operative efficiency, postoperative morbidity and mortality in cardiac surgical operations. In these studies the authors did not measure: (1) the resident's error rate, which may have been higher with sleep deprivation; (2) the role attending physicians or other operating room personnel may have played in averting adverse events when residents erred (3) the mental effort the subjects have invested when they were sleep deprived compared to non sleep deprived status.

Error analysis has been widely performed in laparoscopic surgery but no reported study has focused on the effect of performance shaping factors on errors rate, though it has been identified by laboratory studies (section 1.2.1.1.1). It is difficult to conduct clinical studies investigating the effect of performance shaping factors, such as sleep deprivation, on surgeon's errors rate and postoperative complications. Because it will be considered unethical for a patient to be randomise to a sleep deprived surgeon (Altschuler 1999).

1.2.3 Laparoscopic surgery task analysis

1.2.3.1 Laparoscopic surgery as a hierarchical task

Tasks are undertaken to fulfil a certain task goal. The main task goal is achieved by creating subgoals, which are satisfied first by performing the appropriate actions. The main task goals in surgery are to perform the operation and to avoid complications. In order to carry out laparoscopic cholecystectomy (the main goal), the procedure can be divided into tasks and subtask ((Joice et al., 1998). Joice et al. divided laparoscopic cholecystectomy procedure used at Ninewells Hospital, Dundee, UK; into 10 tasks and each task was subdivided into subtasks (Joice et al., 1998). The first 8 tasks with the subtasks are presented in table 5.

Table 5: Task analysis of Dundee technique of laparoscopic cholecystectomy

No	Task	Plan	No	Subtasks
1	Create CO_2 pneumoperitoneum	Do subtasks in 1.1, 1.2, 1.3consecutive way	1.1 1.2 1.3	Insert veress needle through the abdominal wall into peritoneal cavity Insufflate the abdomen with CO_2 Remove veress needle
2	Insert access ports	Do tasks 2.1, 2.2, 2.3 , 2.4, 2.5 in consecutive order	2.1 2.2 2.3 2.4 2.5	Insert 1st (optical port) Inspect the abdomen Insert 2nd port Insert 3rd port Insert 4th port
3	Dissect and expose cystic duct (CD) and cystic artery (CA)	Do subtask 3.1 if necessary, then 3.2, 3.3, 3.4 in consecutive order	3.1 3.2 3.3 3.4	Dissect adhesions to gallbladder Dissect and mobilise Hartmann's pouch Dissect and isolate CD Dissect and mobilise CA
4	Secure CA and CD	Do subtasks 4.1, 4.2, 4.3 in any order	4.1 4.2 4.3	Place two clips on proximal end of CA Place a clip on distal end of CA Place a clip on gallbladder end of CD
5	Transect CA between clips	Do task 5		
6	Perform operative cholangiogram	Do subtasks 6.1, 6.2, 6.3, 6.4, 6.5 in consecutive order	6.1 6.2 6.3 6.4 6.5	Open antero-superior wall of CD Insert cholangiography catheter into CD Inject contrast – fluorocholangiogram Shoot cholangiogram Remove catheter
7	Secure proximal end of CD by catgut slip knot	Do subtask 7.1, 7.2, 7.3, 7.4 in consecutive order	7.1 7.2 7.3 7.4	Insert long catgut ligature around CD Tie external Roeder slip knot Tighten knot on CD, Cut suture
8	Transect the CD between ligature and clip	Do task 8		

When the task is performed without complications, the main task goals are achieved. In many hierarchical tasks, the task structure includes subgoals that have their own hierarchical structure as well: they include other subgoals.

A hierarchical model supposes that lower-order levels are controlled by higher-order goals. The higher-level goal sets subgoals and behaviour at the tactical level which in turn set the subgoals and actions at the operational level. This implies that a certain action will only be performed when it fulfils a certain (sub) goal. This is an important property of hierarchical tasks. This bottom-up control is an important aspect in all task behaviour. Cao et la., used hierarchical analysis of laparoscopic cholecystectomy and laparoscopic fundoplication procedures (Cao et al., 1999b). They reported that some components of the decomposition of laparoscopic cholecystectomy were serial i.e. they unfolded in sequence (e.g. steps such as isolate gallbladder followed by removal of gallbladder ; and motions such as reach, then orient, then open jaws, then close jaws). Other components were parallel and iterative (e.g. sub-steps such as locate and dissect surround the gallbladder; tasks such as poke and tease tissue). From the hierarchical analysis of the Nissen fundoplication Cao et al., found that, there were four sutures, one anchor sutures, three-and-a-half knots, and five cut sutures in every fundoplication procedure (Cao et al., 1999b).

The hierarchical decomposition approach can be used for several applications in laparoscopic surgery such as:

- Evaluating different aspects of operating room layout e.g. monitor display position.

- Evaluating surgeon's performance, assessing skill levels and learning curves in modular, manageable units.
- Planning customised patient-specific surgery prior to the operation.
- Analysing changes in the surgeon's focus of attention, at each step or level in the hierarchy.
- Understanding what information is used and required by the operating team, and the beneficial ways to present this information during the operation.
- Improve patient safety and decreasing errors (Joice et al., 1998).

1.2.3.2 Laparoscopic surgery as a multi-task activity

In their series Cao et al. divided Nissen fundoplication procedure into seven surgical steps (Cao et al., 1999a): prepare patient, divide peritoneum, expose crura and gastro-oesophageal junction, repair crura, divide short gastrics, wrap fundus and close patient. The steps were further divided into sub-steps, for example the wrap fundus is step included the following sub-steps: elevate oesophagus, pull fundus under, anchor fundus and suture wrap. Each surgical sub-step was broken down into a number of tasks such as dissect, suture, anchor suture, knot and cut suture. They found that sub-tasks making up the suture task were position jaws, bite, pull needle through, re-position, re-bite, re-pull needle through, re-re-position, re-re-bite, re-re-pull needle through and pull suture. Whereas the knotting task is made up of nine sub-tasks: loop, needle under loop, anchor knot, twist and loop, needle through loop, pull knot tight, re-twist and loop, needle re-through loop, and re-pull loop tight.

1.2.3.3 Laparoscopic surgery as a complex task

The added visio motor demands of laparoscopic surgical task make it more demanding and complex than traditional open surgery. Performing laparoscopic surgery requires the use of 2-dimensional information to produce 3-dimensional movements. This requires the ability to transfer a two dimensional image into three dimensional setting in surgeon's mind, and consequently, the ability to appreciate depth perception using very subtle visual clues. The fulcrum point created by the trocars inserted in the body wall limits the internal movement of the instrument tip to four degrees of freedom. This requires fine motor skills and hand-eye coordination as well as precise motor control for manipulating laparoscopic tools that on-screen move in a direction opposite the controlling hand. The mechanical design of video laparoscopic instruments results in substantially diminished tactile feed back which makes the task more complicated especially in advanced procedures.

1.2.4 Evaluation of laparoscopic surgery task performance

Several reliable, valid, and feasible methods of assessing laparoscopic technical skills are reported in the literature. These include video analysis assessment, motion tracking, and virtual reality simulators.

Eubanks et al., developed an Objective Scoring System for Laparoscopic Cholecystectomy (Eubanks et al., 1999). The procedure was divided into 23 steps. A raw score was calculated by adding the points for each of the successfully completed steps. The best possible raw score of 100 was given for the cases with intraoperative cholangiogram and 80 for cases with out cholangiogram. Errors enacted during the procedure were ranked for severity and assigned a relative values ranged from 1 point to 100 points. The final score was calculated by subtracting the error points from the raw score, then dividing the score by the best possible raw score. This value was multiplied by 100 to get the final score as percentage. The simplicity of this system makes it useful in tracking the learning curve of surgeons in training, evaluate the efficacy of alternative training tools, and provide a means of self-assessment for trainee.

The Observational Clinical Human Reliability Assessment system (OCHRA) has been adopted in Dundee from Human Reliability Assessment (HRA) techniques used in industry in order to assess the errors enacted during laparoscopic task performance (Joice et al., 1998; Tang et al., 2004). The OCHRA is based on observational methodology rather than the prediction techniques traditionally used in industry. The high incidence of errors in clinical practice and the ease of capturing the image made the observational methodology more practical. Errors were divided into consequential or non consequential errors. A list of 10 external error modes has been used to describe observed errors. These external error modes were classified according to their causative mechanism into: procedural errors and execution errors. Procedural errors involve omission or rearrangement of correctly undertaken steps within the procedure i.e. the surgeon does not follow the specified steps of the procedure. Execution errors involve the failure of the surgeon to correctly execute an individual step. The OCHRA enables the objective assessment of surgeon's performance and detection of the hazard zone/zones of a specific surgical procedure. However such system needs considerable expertise and resources.

Satava, Cuschieri and Hamdorf- expert laparoscopic surgeons-conducted a workshop to provide a foundation for communication and a standardisation of definitions, measurements, and criteria of assessing surgical competence (Satava et al., 2003).

Time motion analysis of recorded video tapes for laparoscopic procedures was reported in the literature (den Boer et al., 2001; Geryane et al., 2004). den Boer et al., used time motion analysis to analyse the first 25 diagnostic laparoscopies with laparoscopic ultrasonography performed by a surgical resident (den Boer et al., 2001). The results were compared with the outcomes of the same procedure performed by an experienced surgeon. Time motion analysis enables objective measurement of correctness in task performance as well as time and action efficiency.

Several systems are currently available for assessing surgeons' dexterity. Advanced Dundee Endoscopic Psychomotor Tester (ADEPT) is a computer-controlled endoscopic performance assessment system (Hanna et al., 1998a). Francis et al., showed the validity and ability of ADEPT in assessing the innate ability and endoscopic manipulations skills of trainees (Francis et al., 2002). ADEPT provides objective feedback on task performance which facilitates reflective skill acquisition and its assessment by trainees. Imperial College Surgical Assessment Device (ICSAD) is an electromagnetic motion tracking system developed to objectively assess surgical movement (Datta et al., 2001; Moorthy et al., 2003b). ICSAD performs objective measurements of time; path length; number of movements; velocities and trajectories of hands. The advanced version of ICSAD enables synchronized acquisition of hand kinematics and video from real procedures, and their concurrent analysis (Dosis et al., 2005).

Sokollik et al., used an ultrasound tracking system to track the 3D coordinates of the laparoscopic instrument tips (Sokollik et al., 2004). The measured parameters were standardised time and error time as a precision indicator, and the transit profile parameter for spatial perception. The system was able to detect changes of the measured parameters with experience. Emam et al., studied the difference between experts and trainees in the motion pattern of the dominant upper limb during intracorporeal endoscopic knotting using video-based motion tracking system (Emam et al., 2000a). There was a difference in the speed of manipulation and range of movement at the shoulder joint between expert surgeons and trainees.

Virtual reality simulators recently become the worldwide used tool for training and assessment of laparoscopic skills. Studies have shown the validity and reliability of the VR simulators (Taffinder et al., 1998a). As for ADEPT, VR simulators provide real time feedback about skill based errors. However; these systems are currently present low fidelity laparoscopic tasks, therefore; they are effective only in the assessment of basic skills.

Richards et al., compare forces and torques (F/T) applied at the tool/hand interface generated during laparoscopic surgery by novice and experienced surgeons (Richards et al., 2000). The magnitude of F/T applied by novice surgeons and experienced surgeons were significantly different and varied depending on the task being performed. This Preliminary study suggests that F/T measurement can help in training and evaluation of technical proficiency during real laparoscopic procedures.

1.3 Performance of a complex dynamic task in industry

Since laparoscopic task is a complex dynamic task, it is important to discuss the complexities that face the operator in such tasks. This includes a normative task analysis (what do operators need to do), psychological aspects in performing complex tasks and possible cognitive processes involved.

1.3.1 Skill acquisition

The training of subjects to enhance their skill levels is determined by the cognitive, perceptual and motor demands of the task. Although both physical and cognitive skills demand a great deal of training and practice to achieve competence, physical skills are easier to obtain due to their external visibility in carrying out the tasks. It is possible for the trainee to visualise the task and learn through observations. On the other hand, cognitive skills demand a more sophisticated learning process to acquire the experience in handling cognitive tasks. Much of the processes involved in cognitive skills are not visible and run inside human mind. As a result, it is difficult to acquire such skills compared to physical skills. Therefore, understanding task demands forms the basis for skill acquisition of the task. The first step in understanding these demands is an accurate cognitive task analysis which emphases the cognitive, perceptual and motor demands of the task (Lee & Anderson 2001). Such analysis indicates what, how and why operator does.

There are three consequence stages occur during acquisition of motor skills (Kopta 1971). Cognition stage (understanding of the task): trainees who are provided with a clear description and demonstration of the task acquire and master more new skill than those who are not. Integration stage: motor skills unique to the task are applied to avoid inefficient movements. Automation stage: the skill becomes automatic so that there is no need to think about each step during task performance.

Training program should be effective and efficient. These metrics of training systems are affected by the training program schedule. Part-task training approaches suggested that proficiency on the complex task can be achieved via proficiency on the components. The effectiveness of this schedule of training depends critically on how the complex task is broken down and how the task components interact (Lee & Anderson 2001). Skill learning and retention is also influenced by the feedback that the operator receives. Information which is provided by the operator's tactile, auditory and visual feedback is classified as intrinsic feedback. An external feedback supplemented from an external source such as a supervisor or expert is called augmented feedback. The effectiveness of the received feedback on surgical technical skills training has been demonstrated by various studies (Rogers et al., 1998; Rogers et al., 2000).

1.3.2 Situation awareness

Situation awareness is the perception (noticing) of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future (Wright et al., 2004). Three aspects of situation awareness that are most relevant for aviation are three-dimensional (3-D) spatial awareness, system (mode) awareness, and task awareness. These are directly linked to the operator workload and task management. Each of these components has real-world implications, spatial awareness for instrument displays, system awareness for keeping the operator informed about actions that have been taken by automated systems, and task awareness for attention and task management. Task management is directly related to mental workload, as the competing demands of tasks for attention exceed the operator's limited resources (Wickens 2002). Situation awareness is crucial in decision making in complex dynamic tasks (Endsley 1995). The theory of situation awareness can be extended to include team environments, such as would be encountered in a surgical setting. Endsley describes team situation awareness as the degree to which each team member possesses the situation awareness required for his/her responsibilities (Endsley 1995). Team members have individual situation awareness requirements and in some cases these requirements overlap, resulting in shared situation awareness requirements. Cooke refers to shared knowledge between team members in two ways: (1) complementary shared knowledge in which the team members have knowledge that does not overlap but is complementary, resulting in the needed team knowledge; and (2) common shared knowledge in which team members share the same knowledge (Cooke et al., 2000). A team can be considered to have high team situation awareness when all of the individuals on the team possess the situation awareness (whether complementary or shared) required for their respective roles.

1.3.3 Demand on the operator

Complex dynamic tasks, such as air-traffic control, industrial process operation, and medical emergency handling, are characterised by a number of features. These tasks are difficult to perform: they are complex and need coordination, organisation and planning of subtasks (Bainbridge 1997). The human operator in these systems typically performs cognitive tasks such as monitoring, planning, real-time control, and troubleshooting. The operator is ultimately responsible for the safe and efficient system operation. During system operation, the human interacts with the underlying automation and attempts to achieve high level of performance in real-time planning and control tasks.

Furthermore, complex dynamic tasks are performed in dynamic environments where circumstances can change immediately and without warning. Operators therefore need flexibility to adapt their behaviour to new information and situations. At the same time, they need to keep their behaviour goal-directed and resist distraction.

They also need a good mental overview of the task situation to be able to make reliable predictions about the coming situations (Bainbridge 1997).

The same task performance can be achieved by applying different working methods, and each working method may require a different amount of "mental work" (Welford 1978). When operators are confronted with increased task demands, they can either invest more effort, or adjust the performance targets. This means that operators may decrease the desired level of accuracy or speed; use less demanding strategies; or ignore subsidiary activities (Hockey 1997).

1.3.4 Automatic task behaviour

Automatic thoughts and behaviours are ones that occur efficiently, without the need for conscious guidance or monitoring. There are two main categories of automaticity defined by how the thought or behaviour is initiated. Unconscious Automaticity; automatic processes are triggered quite unconsciously, often by stimuli in the environment, whereas Conscious Automaticity require a conscious act of will to get started.

Once the action is well learned, the behaviour becomes automatic in the sense that it does not require constant conscious monitoring. This automaticity allows us no longer to think about the details, and instead to think about the act at a higher level. The development of automaticity involves a shift in brain usage and a reduction in brain activity. Initial processing of tasks is generally procedure based and relies on a series of sequential steps to be completed. The processing of new information makes heavy use of working memory. As skills are repeated, the brain recognizes the information and can process it more quickly and with less effort. Dramatic changes in brain activity can be seen on fMRI scans as automaticity develops. The development of automaticity of skills generally reduces the load of the working memory (Schneider & Chein 2003).

1.4 Mental and physical workload

1.4.1 Mental workload

Growing complexity and increasingly automated features of modern human-machine systems are presenting operators with great cognitive demands. The concept of mental workload is used to scale the mental demands of complex systems. It may refer either to the objective workload imposed by the task or to the subjective ratings of the operator with regard to the demands of the task.

Mental workload refers to the ability of the operator to meet the information processing demands imposed by a task or system and it is related to operator performance (Wilson & Eggemeier 2001). Low to moderate levels of workload are associated with acceptable levels of operator performance, whereas high levels of workload or information processing demand that cannot be effectively accommodated by the operator are associated with degraded levels of operator performance (Wilson & Eggemeier 2001). Thus mental workload is a multidimensional concept, determined by characteristics of the task (e.g. demands, performance), or of the operator (e.g. skill, attention). Optimising the allocation of mental workload to operators could reduce human errors, improve system safety, increase productivity, and increase operator satisfaction.

1.4.2 Physical workload

Physical workload is an important cause of musculoskeletal disorders. There is a strong evidence for a relation between different aspects of physical workload and the occurrence of back, neck, shoulder, and hip pain (van der Windt et al., 2000). Several studies showed that awkward postures result in a higher incidence of musculoskeletal discomfort in a video display terminal tasks (Hunting et al., 1981). Discomfort, fatigue and awkward postures can all decrease forces exerted and undermine precise movement coordination (Pan & Schleifer 1996). Discomfort has an adverse effect on performance (Liao & Drury 2000). Time-on-task plays an important role in the development of discomfort (Hagberg & Sundelin 1986).

1.5 Mental and physical workload measurement

1.5.1 Mental workload measurement

Mental workload measures must have the following properties (Wierwille & Eggemeier 1993):

- Sensitivity: that is how well a metric detects changes in mental workload and it depends on the level of the workload.
- Diagnosticity: the extent to which the technique can reveal the precise nature of the workload.
- Intrusiveness: the used metric should not interfere with the task performance.
- Validity: construct validity considers whether the technique is measuring mental workload, whereas concurrent validity is when different workload metrics correlate in a systemic manner.

- Reliability: describes the replicability of the workload measures under similar conditions.
- Easy to use.

Mental workload is multidimensional and most real-world tasks, such as laparoscopic surgical tasks, are complex and involve multiple task components. Therefore, multiple workload measures are needed to obtain a complete analysis of the mental workload incurred in task performance (Wierwille & Eggemeier 1993). Since mental workload is multidimensional and different workload measures are differentially sensitive to the different workload dimensions, some dissociation among workload measures are to be expected. The understanding of these dissociations can be very helpful in evaluating mental workload.

There are four major categories of empirical mental workload measures: subjective rating, operator performance, psychophysiological measures, and analytic methods (Wierwille & Eggemeier 1993). Subjective measures, which are based on operator judgements of the workload associated with the performance of a task. Performance based techniques, which assess workload through the capability of the operator to perform a task. Physiological metrics, detect changes in the operator's body that are related to task demand.

1.5.1.1 Subjective estimation

Subjective estimation of mental workload is the most widely used human factor tool in industry. The most frequently rating scales used in the evaluation of mental workload are; NASA-TLX (NASA Task Load Index) (Moroney et al., 1995), SWAT (Subjective Workload Assessment Technique) (Moroney et al., 1995), and MCH

(Modified Cooper Harper Scale). These measures are relatively easy to collect, have face validity, and are well accepted by subjects in industry. However, subjective reports are not used in this project for the following reasons: (1) Subjective measures may not provide a complete picture of the cognitive demands placed on the operators (Hankins & Wilson 1998); (2) Subjective reports may be susceptible to memory lapses and bias; (3) Multidimensional rating scales can interfere with the primary task performance; (4) Surgeons are more likely to deny the effects of stress on their performance than pilots and anaesthetist (Sexton et al., 2000); and (5) There is no reported rating scale in the field of medicine.

1.5.1.2 Performance-based measures

The primary task method assesses the actual operator performance. Two major categories of performance based measures are primary task measures and secondary task methodology. In laboratory tasks, motor or tracking performance, the number of errors made, speed of performance or reaction time measures are frequently used as primary-task performance measures. Performance measures are insensitive to very low workload level as a stable level of performance could be maintained by increased effort (Wierwille & Eggemeier 1993). Furthermore; performance degradation such as lower reaction times, decreased vigilance, erroneous decision-making, increased error rates, and fatigue can result when a subject is overloaded or under-loaded. Overload can occur during periods of high mental and/or physical activity, whereas; under-loaded might be seen during long periods of inactivity. Therefore, adding a secondary task (secondary task method) would increase the demand to a level where performance measures would be sensitive.

1.5.1.3 Psychophysiological measures

Different measures have been found to be differentially sensitive to either global arousal (activation level), or to be sensitive to specific stages in information processing. Measures from two anatomical distinct structures are used as physiological indicators: central nervous system measures and peripheral nervous system measures. The central nervous system measures include electroencephalographic (EEG) activity (Fournier et al., 1999), event-related brain potentials (ERPs) (Nittono et al., 2003), magnetic activity of the brain (Jansma et al., 2000), and measures of brain metabolism. The autonomic nervous system is the component of the peripheral nervous system that is responsive to workload manipulation. Examples of autonomic nervous system measures are pupil diameter, heart rate, heart rate variability, and electrodermal measures (Backs & Walrath 1992; Brookings et al., 1996; Richter et al., 1998). Most physiological measures are obtained by attaching small electrodes to the operator, the detected potential are then amplified and recorded for later processing.

There are various advantages of using physiological measures to determine mental workload; (1) They are relatively unobtrusive; assuming of course that users adapt to the few transducers that are affixed to their bodies; (2) Most physiological measures can be recorded in the absence of overt behaviour; (3) Physiological measures are multi-dimensional and can provide a number of views of user mental workload; (4) Since most physiological signals are recorded continuously, they offer the potential for providing measures that respond relatively quickly to changes in mental workload; (5) They have the potential to yield real-time estimates of mental state and; (6) They are relatively easy to implement.

1.5.1.3.1 Heart rate

Heart rate (HR) is probably the most widely used psychophysiological measure as an indicator of mental workload in flight research. The HR typically increases with higher levels of mental workload. The HR is sensitive to the varied cognitive demands of flight (Wilson 2002) and the increase in task difficulty (Fournier et al., 1999; Veltman & Gaillard 1996; Veltman & Gaillard 1998). It is possible that the increase HR reported in flight research can be due to increase physical activity associated with flying. However, Wilson recorded arm movements during flight and reported very low correlation with the pilots' HR (Wilson 2002). Electromyographic (EMG) data were also collected and were not highly correlated with HR or electrodermal activity.

1.5.1.3.2 Heart rate variability

Heart rate variability (HRV) is a measure of the oscillation of the interval between consecutive heartbeats. This measure is expressed in terms of consecutive cardiac cycles. Such terms include: cycle length variability, heart period variability, R-R interval variability (referring to the beat-to-beat interval formed by consecutive R-waves of the cardiac signal), and the R-R interval tachogram (Malik 1996).

The use of HRV in evaluation of mental workload is valued not only because of its nonintrusiveness, but also because of its utility where continuous recording is required (Tattersall & Hockey 1995). The HR and HRV were found to be sensitive to different phases of the work environment. The HRV is consistently responds to changes from rest to task conditions and to a range of between-task manipulations (Aasman et al., 1987; Sirevaag et al., 1993). In laboratory studies, HRV is gaining broad acceptance as an indicator of the extent of task engagement in information processing requiring significant mental effort (Sirevaag et al., 1993; Tattersall & Hockey 1995; Wilson 1993). The HRV is an accurate measure of the amount of mental effort being invested by a subject (Vicente et al., 1987). The HRV usually responds rapidly, within seconds, to changes in user mental workload (Aasman et al., 1987).

Several laboratory studies have indicated that spectral analysis of the cardiac interval signal can provide indices of HRV that reflect changes in operator effort or task engagement (Aasman et al., 1987; Vicente et al., 1987).

Van Amelsvoort et al., used HRV to determine the differential effects of forward and backward rotating shift schedules on circadian cardiac autonomic control (van Amelsvoort et al., 2001). They reported that working nights causes a shift of the autonomic balance towards sympathetic dominance especially for workers with an anti-clockwise (or backward) rotating work shift schedule. This shift in the autonomic balance might be a component in the elevated cardiovascular disease risk of shift workers. Bohm et al., compared the mental strain of the surgical team during laparoscopic and conventional sigmoid resections using heart rate variability (Bohm et al., 2001). They continuously recorded the electrocardiograms of the surgeon and assistant during the procedures and heart rate variability was analysed off-line. In their series, they reported that performing laparoscopic colorectal surgery causes higher mental strain in surgeons than performing conventional surgery.

Power spectral density analysis of the electrocardiogram provides information on how power (i.e. variance) distributes as a function of frequency. Spectral components of the cardiac interval signal for short-term changes (about five minutes) in HRV fall into three frequency bands (Berntson et al., 1997; Bohm et al., 2001; Malik 1996): Very low frequency band (≤0.04 Hz), Low frequency band (0.04-0.15 Hz) and High frequency band (0.15-0.4 Hz). The low frequency band has been termed as mid frequency band by some authors (Aasman et al., 1987) but the designation of low frequency is used in this project. The low frequency band; also known as (0.10 Hz) component has been more consistently found to be sensitive to demands for increased mental workload, because it correlates with subjective estimates of workload (Aasman et al., 1987). An increase in mental workload is typically associated with a reduction in the power associated with mid-frequency component, implying a temporary suppression of normal arterial pressure regulation. Literature seems to suggest that certain components of heart rate variability (HRV) exhibit systematic and reliable relationships with task demands (Fournier et al., 1999; Tattersall & Hockey 1995; Vicente et al., 1987). According to Jorna HRV is a promising measurement, being however more complex to assess and therefore less often used, especially in dynamic task environments (Jorna 1993).

1.5.1.3.3 Eye blinks

The endogenous eye blink is defined as a cortically controlled response event (Stern et al., 1984). Endogenous eye blink is distinguishable from both reflex blinks and voluntary blinks. Reflex blinks; the stimulus-elicited involuntary (reflex) blink is a protective response which occurs to stimuli potentially injurious to the organism (e.g. loud noise or a tap to the forehead). Voluntary blinks; occurs in response to an identifiable stimulus, either self-initiated or at the request of an examiner. Non-blink closure; such that associated with the onset of sleep.

The endogenous eye blink has a characteristic rate, form, and temporal distribution which are related to cognitive state variables. Endogenous eye blink parameters are indices to allocation of attentional resources, transition points in information processing flow, and possibly processing mode (Stern et al., 1984). Stern et al., has also reported that parameters of the endogenous blink are sensitive indicants of cognitive activity. Fogarty and stern concluded that endogenous eye blink is triggered by aspects of information processing, and that blink parameters can be used as one tool for evaluating the level of complexity of such processing under a wide variety of task demand (Fogarty & Stern 1989).

A variety of techniques are available to measure eye blink, such as video scanning and electrooculogram (Tsubota et al., 2002; Veltman & Gaillard 1998). Electromyographic activity from orbicularis oculi muscles can also be used to record eye blink (Neumann 2002; Stern et al., 1984). When eye blinks derived from electrooculogram (EOG) the following parameters can be distracted from the signal: number of blinks per minute (blink frequency), blink interval, closing time, duration and amplitude (Veltman & Gaillard 1998). Blink interval is the time between two successive eye blinks. The duration of a blink extends from the point when the EOG signal attained half of its maximum amplitude during eye closing, to the point when the signal crosses the same voltage level in the reopening phase. The amplitude is calculated from the start of a blink to the lowest point in the signal.

Visual tasks required subjects to inhibit blinking for high efficiency of information processing (Stern et al., 1984; Veltman & Gaillard 1998). Veltman and Gaillard reported that blink interval increased; whereas blink duration and closing time decreased as more visual information had to be processed. However, increases in mental workload by manipulating memory set size led to decrement in blink interval (Veltman & Gaillard 1998; Yamada 1998). They attributed this to the subvocal activity during rehearsal of target letters. Bauer et al., and Stern et al., found an increase in blink interval while performing a cognitive activity like arithmetic (Bauer et al., 1987; Stern et al., 1984).

Blinking rate was used by Berguer et al., to study the difference between open and laparoscopic surgery and they found an increase in blinking rate and skin conductance level during laparoscopic task performance (Berguer et al., 2001c). They reported that performing laparoscopic surgery is significantly more stressful for the surgeon than open surgery.

1.5.1.3.4 Electrodermal measures

There are two principal components of skin conductivity: Galvanic Skin Response: changes in resistance of a short duration which typically reach a peak in two or three seconds. Skin Conductance Level (SCL): a baseline conductivity level which may change slowly (drift) with time.

Galvanic Skin Response is a measure of the skin's conductance between two electrodes. Skin conductance is typically measured by applying a small alternating current (AC) signal through two electrodes, placed on the fingers or toes, and the response is seen as a change in conductance (decrease in resistance) of the skin with time. The change in conductance is a function of sweat gland activity and the skin's pore size. An increase in conductivity arises through increased skin moisture, pre-secretory activity of the sweat gland cell membranes or both. Skin conductance can vary because of activity of the subjects' autonomic nervous system, or more specifically, their sympathetic nervous system. Activity of these glands is sensitive to respiration; temperature; humidity; age; sex; time of day; season; arousal and emotions. The main problem with electrodermal activity measures are a global sensitivity. Therefore; all behaviour (emotional as well as physical) that affects the sympathetic nervous system can cause a change in electrodermal activity. Berguer et al. used skin conductance activity to investigate the mental demand of open and laparoscopic surgery on surgeons (Berguer et al., 2001c). In their series they reported that performing laparoscopic surgery is significantly more stressful for the surgeon than open surgery. This was indicated by the increase in blinking rate and skin conductance level during laparoscopic surgery.

1.5.2 Physical workload measurement

1.5.2.1 Subjective estimation

Although it is not possible to quantify the workload and only simple estimations of the amplitude, frequency, or duration of workload can be made, information collected by questionnaire may be sufficient to rank the physical workload of specific activities, tasks, or jobs (Burdorf & van der Beek 1999).

Several questionnaires on physical workload have been developed and most of these are composed of various items relating to physical load (for example, posture, manual handling loads, repetitive movements, static load). These items are either summed (Hollmann et al., 1999) or analysed separately (Leijon et al., 2002). Some questionnaires are divided into several subscales (Pope et al., 1998; Wiktorin et al., 1996). Pope et al physical workload measuring questionnaire contains three subscales (working postures, manual handling activities, and repetitive movements of the upper limb) (Pope et al., 1998). Wiktorin et al questionnaire includes thirty three questions concerning occupational workload and are divided into six subscales (working postures involving whole or parts of the body, manual material handling, vibration, physical activity, exertion) (Wiktorin et al., 1996).

1.5.2.2 Measurement of posture

Posture can be described geometrically in three different ways: by three-dimensional co-ordinates of individual joints, by defining the orientation angles of the long axes of body segments in space, or by recording these orientation angles relative to the proximal body part (anatomic method).

The various recording techniques used to measure the posture provide the following basic types of posture parameter (Haslegrave 1994):

- Location of major body joints; these must be approximated by surface reference points which can be palpated. Recently the availability of acoustic, optoelectronic and electro-magnetic sensors allowed the recording of three-dimensional co-ordinations in space.
- Body joint angles
- Body part location relative to a standard posture (posture targeting): this is an observational technique providing an unscaled estimate, which essentially combines the locations of major body joints angles.
- Posture and movement notation.
- Classification of posture types such as Armstrong's recording system for hand and arm posture. This is coding system which is very useful for the identification of poor postures according to predefined criteria.
- Body outlines using photographs, video records or sketches.

Laparoscopic surgery has changed the way surgeons interact with the surgical field and therefore it has changed the surgeons' posture. Performing laparoscopic surgical procedures requires the surgeon to assume awkward body positions for a significant period of time. These uncomfortable and potentially harmful postures adapted by the surgeons can cause static muscle loading and fatigue (Corlett & Bishop 1976) as well as impaired psychomotor task performance (Bhatnager et al., 1985). Laparoscopic surgeons experience extreme muscle fatigue and chronic injury as a result of their position during laparoscopic task performance (Berguer et al., 1997; Berguer et al., 1998; Cuschieri 1995).

Berguer et al., used the video-based motion analysis technique to compare the head and back posture of the surgeon during laparoscopic and open procedures in laboratory and real settings (Berguer et al., 1997). In the laboratory study the authors studied the position of head, trunk and pelvis of 4 subjects during simulated surgical task under direct vision and laparoscopic set up. Twelve reflective markers placed on the posterior aspect of subjects' head, shoulders and pelvis. Three video cameras were used to record the position of the markers. Motion analysis software was used to calculate the anteroposterior flexion, lateral bending and rotation of the head to the trunk, the trunk to the pelvis, and the pelvis to the workspace floor. In the second study the authors videotaped the surgeons from the knee to the head during 4 laparoscopic and 6 open operations in the operating room. A computer programme was used to record each time the surgeon's head and back changed by pressing one of eight preassigned keys on the computer keyboards. They suggested that surgeons exhibit decreased mobility of the head and back, less anteroposterior weight shifting and more up right posture during laparoscopic manipulations.

Nguyen et al videotaped 16 operations (8 laparoscopic and 8 open) performed by 5 surgeons (Nguyen et al., 2001). The video provided only a single frontal view of the surgeon's head to pelvis. The videotapes were reviewed to record the numbers of the subjects' neck, trunk, shoulder, elbow, and wrest movements. A single specific movement of these body parts was defined as deviation of the body posture from the neutral upright body position and included its return to the neutral body position. They reported that laparoscopic surgery involves a more static posture of the neck and trunk, but more frequent awkward movements of the upper extremities than open surgery.

Another video-based motion analysis system (Kinemetrix model 5.0-3D/3MBM; MIE Medical Research Ltd., Leeds, England) was used by Emam et al., to record the shoulder and elbow angles and the supination and pronation of the forearm during simulated laparoscopic task performance. The system consists of three infrared sensitive video cameras and associated computer, calibration frame, software, and displays. Each camera lens is surrounded by an array of forward-pointing infrared light emitting diodes. These illuminate retro reflecting markers (placed on specific sites on the test subjects), which appear with very high contrast in the video image. Each video frame is analysed by dedicated software to find the three dimensional coordinates of the centre of the markers. Further software analysis provides the angles formed by marker triplets and derived values such as velocity and angular velocity (Emam et al., 2001).

Vereczkei et al also used a video-based technique to assess the effect of monitor location on the surgeon's posture in the operating room during laparoscopic cholecystectomy (Vereczkei et al., 2004). A simultaneous and synchronised video recording of surgeons' posture were done using two miniDV digital camcorders with the cameras standing at a 90° angle to each other. Later, using the time codes of the recordings, all were analysed, different steps of the operation were identified, and the duration of these steps was measured in seconds. The digitalised pictures were further analysed using software (PCMAN software) to measure the rotation, lateral, and anteroposterior movements of joints and parts of the body.

1.5.2.3 Measurement of muscle recruitment

Fatigue has been studied using electromyography (EMG) in which there is a characteristic increase in the width and duration of the action potentials due to the recruitment of additional motor units. In muscle fatigued by repeated contractions, there is a decrease in the electromyographic signals, but an increase in the amplitude of the electromyogram. This phenomenon reflects an increase in the amplitude and duration of the potentials and in the recruitment of additional motor units (deVries et al., 1982; deVries et al., 1990). Integrated EMG has been used by several authors to describe muscle recruitment (Emam et al., 2001; Iwanaga et al., 2000; Saito et al., 1997).

Berguer et al., studied the effect of the laparoscopic instrument working angle on surgeons' upper extremity workload (Berguer et al., 2001a). Electromyographic signals were collected from the thenar compartment, flexor digitorum superficialis, and deltoid muscles of the dominant arm of 8 surgeons while they were closing a standard pistol-grip disposable laparoscopic grasper against a fixed resistance of 3 N. The instruments' position was randomly changed among 15°, 45°, and 75° of horizontal angulation relative to the surgeons' sagital plane, and 15°, 45°, and 75° degrees of vertical angulation relative to a horizontal plane. EMG signals were rectified and smoothed using analogue circuitry and digitally sampled at l0 Hz. No normalisation method was reported in the study which might indicate the use of the raw rectified EMG data.

Matern et al., studied the effect of monitor location during simulated laparoscopic task performance on electromyographic activity of the main neck muscles (sternocleidomastoid, left side; trapezius, both sides; and paravertebral neck muscles measured above vertebra C2-C4, both sides) (Matern et al., 2005). The EMG sampling rate was 500 HZ. EMG activity was quantified using the root mean square (RMS) per minute of the rectified EMG signal. EMG values of the tests for each muscle were expressed as a percentage of the maximal voluntary EMG activity of the respective muscle. The maximum voluntary EMG activity was assessed by maximally pressing the head for 30 sec against a resistance in anterior, posterior, and rotation to the right.

Uhrich et al., assessed the effect of monitor location and surgeon's experience on muscle fatigue during 4 simulated laparoscopic tasks (Uhrich et al., 2002). Eight male surgeons performed each task 10 times. EMG was recorded for 30 seconds during the 1st and the 10th run. The investigated muscles included upper trapezius, sternocleidomastoid, middle trapezius, anterior deltoid, lower erector spinae, and hamstrings. The root mean square (RMS) was calculated from 1 second sample for each 30 second trial. Electromyogram was also recorded for 5 seconds during maximum voluntary contraction (MVC) and seated resting periods. The RMS was normalised using the following formula:

nRMS = (task RMS - baseline RMS)/(MVC RMS – baseline RMS).

Emam et al. used the MT8 radiotelemetry system to study the effect of laparoscopic needle holder handle design on muscle recruitment during simulated laparoscopic suturing (Emam et al., 2001). The MT8 radiotelemetry system is a wireless precalibrated EMG system (MIE Medical Research Ltd.). It incorporates Myo-Dat software, which collects up to eight channels of data. The data are analysed by the software to provide integrated EMG, frequency spectra, activity spectra parameters. The authors used integrated EMG as an index of total muscle work and Delta-m spectrum as a measure of fatigue. Recording time, land markers of the electrodes locations, inter electrodes distance, and normalisation method of the raw integrated EMG were not reported.

1.6 Selection of methods

1.6.1 Mental workload

From section(1.5.2) it is obvious that psychophysiological measures are the only reported mental workload measures that have been used in the field of surgery (Becker et al., 1983; Berguer et al., 2001c; Bohm et al., 2001; Czyzewska et al., 1983). Due to the complex nature of laparoscopic surgery, it is unreasonable to expect any one measure to provide a complete assessment of the surgeons' workload state. Therefore; a battery of measures is recommended. The psychophysiological measures used in this thesis were: heart rate, heart rate variability, skin conductance level and blinking rate.

Heart rate and heart rate variability were the only measures used in the first and second experiments (section 2.1.2.7) which investigated the effect of image display size and viewing distance and the effect of gaze down set up on mental workload and performance respectively. Skin conductance was not used as a mental workload measure in the first and second experiments because we found that when we attached the electrodermal activity recording electrodes to the subjects' non dominant hand during the familiarisation trials they interfered with the subjects' ability to perform the interrupted bowel suturing. This is because the interrupted bowel suturing is a bimanual task. Blinking rate was also not used in the first and second studies because the task was interrupted bowel suturing and therefore the change in the subject's gaze between each stitch can influence their blinking rate. In the third study (section 2.3.2.3) Dundee Endoscopic Psychomotor Tester (DEPT) was used as a laparoscopic task. As DEPT execution time can be less than 5 minutes, heart rate and heart rate variability were not used with DEPT. This is because electrocardiogram should be continuously recorded for a minimum of 5 minutes in order to obtain the heart rate variability analysis (Malik 1996). Therefore skin conductance and blinking rate were used in the third study.

In the fourth study (section 3.2.5.1) blinking rate and skin conductance were used to measure subject's mental workload while performing a pick and place task under direct vision, two dimensional and three and three dimensional laparoscopic imaging systems. As the chosen pick and place task can be completed in less than 5 minutes time, heart rate and heart rate variability were not used.

Skin conductance and blinking rate were used in the fifth study in the project (section 4.2.2.2) which investigates the effect of training on mental workload, physical workload and performance. Heart rate and heart rate variability were not used because the portable electrocardiogram recording system was not available when we have started the study. Skin conductance, heart rate, heart rate variability were used in the sixth study (section 4.1.2.3).

In the clinical part of the thesis heart rate and heart rate variability were used to measure surgeons' mental workload. This is because electrocardiogram recording does not interfere with the task performance, acceptable by surgeons and easy to perform. Electrocardiogram recording is the only continues mental workload metric used in the operating room.

1.6.2 Physical workload

We have tried to use Kinemtrix motion tracking system to assess the effect of image display location on the subjects' posture (section 1.5.2.2) but we faced some technical problems in the hardware of the system. The hardware of the kinemetetrix system could not download the recorded data when we used it for more than 1 minute of recording time. As our target was to obtain continuous recording of the subjects' posture, kinemeterix system was not used. However, body positions at the different monitor location were studied using a video-based technique (section 2.1.2.5).

Muscle workload was assessed using integrated electromyogram data of selected muscles (section 1.5.2.3). In the study investigating the effect of image display location on physical and mental workload, sternocleidomastoid, trapezius, erector spinae, and deltoid muscles were selected (section 2.1.2.6). In the study investigating the effect of training on mental and physical workload flexor compartment, extensor compartment, biceps, deltoid, and triceps muscles of the dominant hand were selected (section 4.2.2.2).

1.7 Conclusions from literature review

Operating room layout affects surgeons' ability in performing laparoscopic tasks. All the reported research assessed the influence of image display location in relation to surgeon's workplace on task performance and muscle workload but there are no reports on the influence of image location on mental workload. Also, there is no available data on the influence of image size and its viewing distance on physical workload, mental workload and task performance.

Current laparoscopic imaging modalities degrade task performance compared to human vision and the current technology of 3-dimensional imaging systems did not show significant influence on task performance in the majority of studies. However; the influence of imaging modality on the processing of obtained information and mental workload is missing.

Furthermore; laparoscopic task performance is presenting novice surgeons with great physical and mental demands. No studies investigated the affect of training on physical and mental workload in laparoscopic surgery.

Several studies assessed the quality of surgical operative performance by documenting the errors, the stage of the operation in which errors are enacted most frequently, and where these errors have serious consequences. However; no reported studies have investigated the relation between surgeon's mental workload and errors enacted during different stages of a laparoscopic procedure in the clinical setting.

1.8 Aims of project

Performing laparoscopic procedure is a highly complex task that requires the surgeons to be proficient in numerous skills. Surgery is a dynamic pursuit that at times can place great demands on the surgeon's cognitive and physical capabilities. High levels of cognitive demand can lead to errors with catastrophic outcome. Increasing our knowledge of the effects of the various demand levels encountered during laparoscopic procedures can help avoid errors. It is necessary to design systems and develop training regimens and that will reduce cognitive demands to not exceed the capacities of the operating team. Data from clinical and laboratory studies can help us develop an understanding of the usual demands placed on operating team. This information can assist us in forming the standard against which future data are compared. It also permits comparisons with data from unusual circumstances. This requires measures that are sensitive to cognitive workload so that one can assess the effects of task demands on the surgeon. Accurate assessment of surgeons' workload is an important step in identifying vulnerabilities in complex health care systems. By understanding how various performance shaping factors impact surgeons' workload and performance, experts can better design systems and training to prevent adverse effects, thus improving safety.

Human factors research in other high-risk fields has demonstrated how studying of factors that affect job performance can lead to improved outcome and reduced errors after evidence-based redesign of tasks or systems.

Our main hypothesis was: improving the currently available operating room lay out and image processing systems; and surgeons' training can decrease surgeon's workload and improve their performance. Therefore, the aims of the project were:

I. To investigate the influence of image display system related factors on surgeon's mental and physical workload and endoscopic task performance such as:

- Image size;
- Viewing distance and
- Image location in relation to surgeon's workspace (operating field).

II. To investigate the effect of imaging modality (two dimensional and three dimensional) on surgeon's mental workload and performance.

III. To study the effect of training on mental workload, physical workload and skill acquisition in laparoscopic surgery.

IV. To study the effect of innate ability and task repetition on mental workload and skill acquisition in laparoscopic surgery.

V. To describe errors rate and surgeon's mental workload during different stages of laparoscopic cholecystectomy in the clinical setting.

CHAPTER TWO

INFLUENCE OF LAPAROSCOPIC IMAGE PLACEMENT ON PHYSICAL WORKLOAD, MENTAL WORKLOAD AND TASK PERFORMANCE

2. INFLUENCE OF LAPAROSCOPIC IMAGE PLACEMENT ON PHYSICAL WORKLOAD, MENTAL WORKLOAD AND TASK PERFORMANCE

The image display system is the only visual interface between the surgeon and the operative field. It has been shown in section (1.2.1.2.1) of the literature review that the location of the image display in relation to the surgeon and the operative field has a great influence on surgeon's performance and physical workload. Placing the image display at the operative field improves surgeon's performance and influences surgeon's posture and neck muscle activity. However, the later two factors were not explored thoroughly in the literature.

Whilst effect of gaze down set up has been widely studied, the potential effect of viewing distance and image size has not been explored. Furthermore, the effect of image display location on surgeon's mental workload has not been identified yet.

Three studies are included in this chapter. The first study (section 2.1) and the second study (section 2.2) have the same materials and methods except the image display location. The first study investigate the following two hypotheses: (1) Placing the image display at the eye resting position (100 cm viewing distance) decreases surgeon's workload and improves task performance (2) Large displayed image is superior to small image in terms of surgeon's workload and performance. In the second and third studies (sections 2.2 and 2.3) we hypothesised that placing image display at the operating field decreases surgeon's mental and physical workload and hence improve his/her task performance.

2.1 Effect of image size, viewing distance and vertical gaze on surgeon's physical workload, mental workload and task performance

2.1.1 Aim

The aim of the study was to test the following two hypotheses: (1) Placing the image display at the eye resting position (100 cm viewing distance) decreases surgeon's workload and improves task performance (2) Large displayed image is superior to small image in terms of surgeon's workload and performance.

2.1.2 Materials and methods

A within-subjects design experiment was performed to investigate our hypothesis.

2.1.2.1 Subjects

Ten surgeons with varying degree of laparoscopic experience participated in the study by performing the viewing distance and image size experiment and gaze down experiment. The subjects aged 34-38 years (mean = 35 years). All participants were right-handed with normal or corrected-to-normal vision. Each subject completed the study in two sessions over two consecutive days. Each surgeon completed two laparoscopic tasks with a six studied conditions. The order of the studied conditions for each surgeon was in a random sequence.

The experimental session for each subject was divided into: (a) time for attaching electrodes to the subjects; (b) baseline recording period (c) instruction period to familiarise subjects with experimental set up and tasks; (d) test periods; (e) 15 minutes break between each condition. During each test period surgeons' heart rate, heart rate variability and posture were recorded continuously during the bowel suturing task, whereas electromyogram was recorded for 1 minute at the beginning, after 15 minutes, and at the end of the bowel suturing. Heart rate and heart rate variability were recorded during each rest period.

2.1.2.2 Monitor positions

Monitor was placed at three viewing distances relative to the surgeon's eyes:

- 60 cm-The minimum preferred viewing distance for visual display units (Jaschinski et al., 1998)
- 100 cm-The maximum preferred viewing distance for visual display units (Jaschinski et al., 1998).
- 150 cm-Derived from the operating room set-up with the monitor on a tower next to the operation table (Veelen et al., 2002).

At each distance two monitor sizes were investigated; small size monitor (14 in, Sony, Tokyo, Japan) and large size monitor (20 in, Sony, Tokyo, Japan). In each condition monitor height was adjusted so the middle of the monitor was at the level of the surgeon's eye. A special monitor stand was used to adjust each monitor location.

2.1.2.3 Tasks

2.1.2.3.1 Laparoscopic bowel suturing task

This task entailed closure of 50mm small bowel enterotomy. The enterotomy was placed along the antimesenteric border of a 100-mm piece of porcine small bowel clamped to a nonreflective surface inside a trainer box. Each participating surgeon was instructed to close the enterotomy with interrupted intracorporeal surgeon's knot, using 180 mm 3/0 Polysorb on a 23-mm ski needle (EL-415, USSR; Auto Suture

European Services Centre S.A., Elancourt, France). The surgeons were asked to drive the needle into the tissue 5 mm from the edge and 5 mm from each other and to use each thread to perform two stitches only. In the first experiment each surgeon performed one enterotomy closure under two image sizes and three viewing distances. In the second experiment each subject performed one enterotomy closure under two different levels of monitor height (eye level and ports level). Physical workload and mental workload were measured during task performance.

2.1.2.3.2 Intracorporeal laparoscopic knot tying task

This standardised task consisted of tying an intracorporeal surgeon's knot using a 200-mm length of 2-0 silk inserted through a block of yellow foam (Figure 4). A longitudinal groove in the middle of the back of the foam housed a rubber tube. The thread was passed through the foam around the tube with a distance of 10 mm between the entry and exit points. The assembled task rig was placed inside a trainer in which the front and the top were made of cardboard. Strips of neoprene were sutured to the cardboard to allow maneuverability of the instruments while retaining the port positions (Hanna et al., 1998c). In the first experiment each surgeon performed 4 knots under two image sizes and three viewing distances. Therefore each surgeon performed 24 knots in total. In the second experiment each surgeon performed 4 knots under gaze down monitor location and 4 knots under eye level monitor location. Physical workload and mental workload were not measured during the performance of this task, because the task was very short.

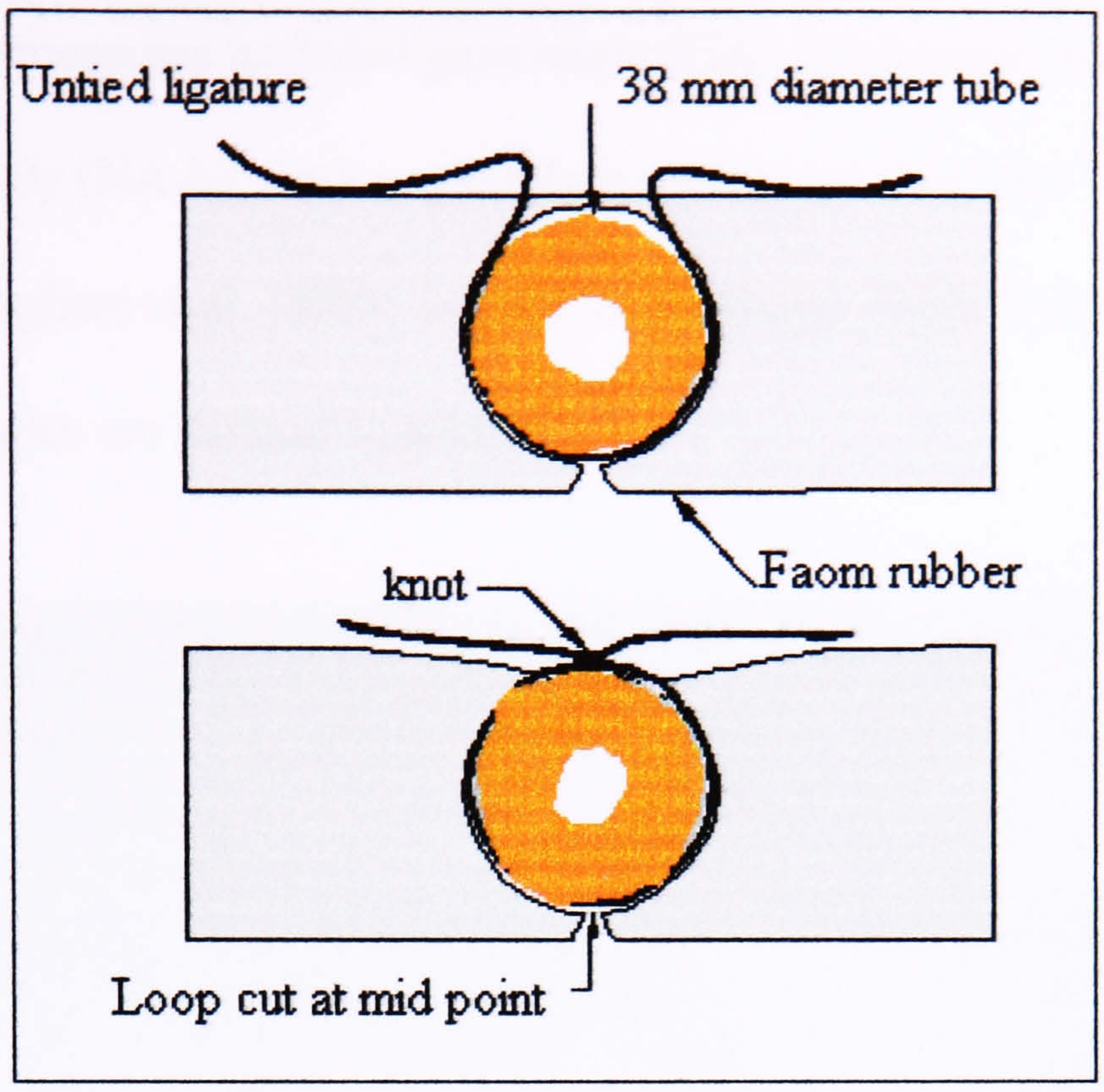

Figure 4: Foam block with a thread mounted around rubber tube

2.1.2.4 Videoendoscopic equipment

The videoendoscopic system consisted of a forward-viewing endoscope 10 mm in diameter coupled to a single-chip camera (Endovision 9050-PB, Karl Storz, Tuttlingen, Germany), a light source and a light cable (Karl Storz) and a high-resolution monitor (model PVM-1443MD, Sony, Tokyo, Japan). .

2.1.2.5 Posture assessment apparatus

Body positions at the different monitor location were studied using an infrared camera. The infra red camera was placed orthogonal to the subject and connected to a video camera recording system for continues recording of subject's posture from the left profile of the subject through out each set up. Reflective markers were placed at the canthus, tragus, C7, inferior wing of the scapula, and greater trochanter (Figure

5). Participants were instructed to stand with their heels on a line drawn on the ground. Posture measures included gaze angle (GA), head angle (HA), neck angle relative to the body (NA-b), neck angle relative to the vertical (NA-v), and thoracic bending (Tb) (Seghers et al., 2003; Straker & Mekhora 2000; Villanueva et al., 1996). Those angles are defined in table 6.

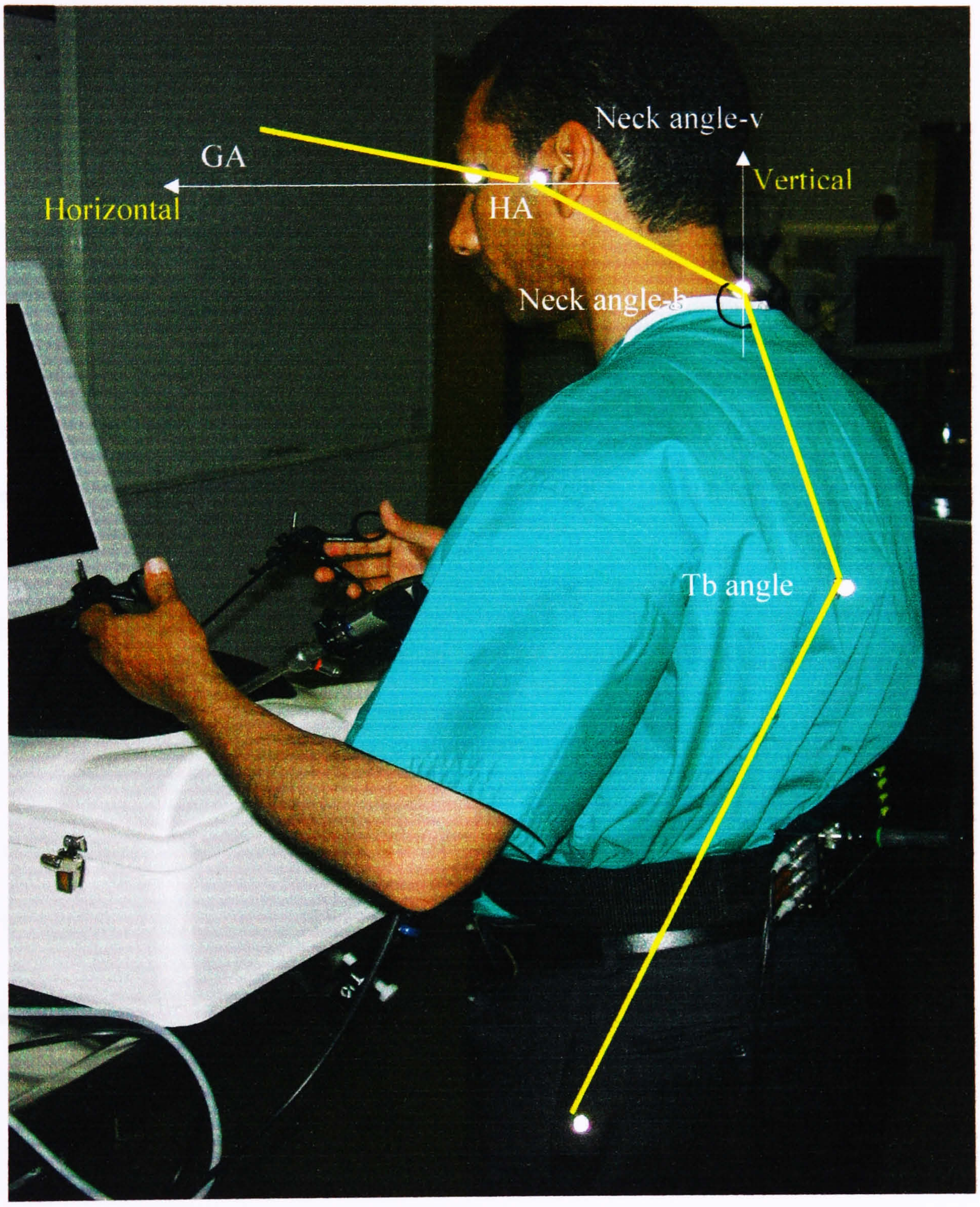

Figure 5: Location of the markers and measurement points for body posture

Table 6: Selected postural angles

Angle	Definition
Viewing angle	The angle formed by the viewing distance line, a line from the eye to the centre of the monitor, and the horizontal plane. This angle was measured using a plastic goniometre during the set up of the experiment only, i. e. at the beginning of each session.
Gaze angle (GA):	The angle between the ear-eye line, a line from the tragus to the external canthus, and a horizontal line. An angle below the horizontal was defined as a negative angle.
Head angle (HA):	The angle between the ear-eye line and tragus-C7 line, a line from the tragus to C7.
Neck angle relative to the body (NA-b)	The angle between the tragus-C7 line and C7-scapula line (the line between C7 and lower angle of the left scapula).
Neck angle relative to the vertical (NA-v):	The angle between the tragus-C7 line and the vertical.
Thoracic bending angle (TB):	The angle between greater trochanter-scapula line (the line between greater trochanter of left hip and scapula) and scapula-C7 line.

For postural analysis the video tapes were digitised using Dazzle Digital Video Creator 80 (SCM, USA) and sampled once per minute, providing 30 data points per subject per monitor location. To analyse the change in posture over time images were digitized from the recorded tapes on the first, third and sixth 5-minute and sampled once per minute, providing 5 data points per 5-minute period per monitor location for each subject (Seghers et al., 2003; Turville et al., 1998). UTHSCSA ImageTool (UTHSCSA ImageTool, University of Texas Health Science Centre, San

Antonio, Texas, USA), image processing and analysis program, was used to measure the postural angles.

The position of the head relative to the environment was described by inclination of gaze angle (GA). Sagittal movement of the head about the atlanto-occipital joint was described by the head angle (HA). Sagittal movement of the neck about the cervical joints was described by the neck angle relative to the body (NA-b) and neck angle relative to the vertical (NA-v). The trunk posture was measured using the thoracic bending angle (Tb).

2.1.2.6 Muscle workload assessment apparatus

MT8 Electromyographic radiotelemetry system was used to measure muscle recruitment. The MT8 radiotelemetry system is a wireless precalibrated EMG system (MIE Medical Research Ltd, Leeds UK). It incorporates Myo-Dat software, which collects up to eight channels of data. The data are analyzed by the software to provide integrated EMG, frequency spectra, activity spectra, and other parameters. Integrated EMG was used in this study as the measure of muscle workload. Integrated EMG is the summation of EMG signals from specific muscles or group of muscles during the test after being full-wave–rectified and low-pass–filtered (0.6 Hz). The EMG parameter used in the study was the integrated EMG as an index of total muscle workload.

The signals generated by the right sternocleidomastoid, the right trapezius, right erector spinae and the right deltoid muscle were recorded. Two self-adhesive surface rectangular electrodes (Red Dot, 2239; 3M Health Care, Postfach, Germany), were placed over each group of muscles according to the recommended locations for surface electrode leads for the selected muscles, along the muscle fibres direction, with inter-electrode distance of 1 cm (Table 7). Self-adhesive surface circular electrodes each of 60-mm diameter were used as common ground electrodes. These muscles were selected because shoulder muscles are common sites of chronic, work related myalgia (Hagberg & Wegman 1987) and surgeons exhibit more static posture of the neck and trunk with a trend of more shoulder stiffness after laparoscopic surgery compared to open operations (Nguyen et al., 2001). Prolonged muscle loads, especially in the shoulder-arm region and the trunk, are expected to occur in the stabilisation of the body posture.

Table 7: Anatomical land markers for the electrodes placement (Elfving et al., 1999; Hui et al., 2001; Luttmann et al., 1996; Zipp P 1982)

Muscle	Electrode locations
Sternocleidomastoid	1/3 the length from the mastoid process to suprasternal notch
Trapezius	Midway between the spinous process of C7 & the acromion
Deltoid	1/4 the line from the acromion to the lateral epicondyle of the humerus
Erector spinae	3 cm lateral to the spinous process at L5

2.1.2.7 Mental workload assessment Apparatus

Heart rate (HR) and heart rate variability analysis (HRV) were used as methods of evaluating mental workload in this study (Table 7). To perform the HRV analysis, an electrocardiograph (ECG) signal was measured. The inter-beat-intervals (IBI) are derived from the ECG as the intervals between consecutive R peaks. Heart Rhythm Scanner system (Biocom Technologies, Washington, USA) was used for measuring and evaluating heart rate variability (HRV). The system records HR signals, computing the instantaneous changes in heart rate, and provides full analysis of heart rate variability after the session is complete. For the ECG recording, three self-adhesive surface circular electrodes (Red Dot, 2239; 3M Health Care, Postfach, Germany), each of 60-mm diameter, were used. One electrode was placed below the jugular notch and a second electrode between the ninth and tenth rib on the left side of the rib cage. A common ground electrode was placed between the ninth and tenth rib on the right side of the rib cage.

Heart Rate Variability measures the time intervals between each two consecutive heartbeats, which vary under control of the autonomic nervous system. The standard mathematical procedure for short-term HRV evaluation, was suggested by the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (Malik 1996). It provides both time and frequency domain analysis of the IBI time series. There are three important parameters of frequency domain analysis within HRV that reflect the levels of sympathetic and parasympathetic activity and their balance. The high frequency range (0.15 Hz – 0.40 Hz) of the IBI power spectrum (HF) reflects parasympathetic influence on heart rate. The low frequency range (0.04 Hz – 0.15 Hz) of the IBI power spectrum (LF) displays sympathetic influence. The LF/HF ratio is used to show the balance between both branches of the autonomic nervous system. To minimise the effect of very low frequency band changes on the low and high frequency bands, normalised low frequency (Lfn) and high frequency (Hfn) measures were used (Table 8). Normalised low frequency and high frequency are calculated in percentile units.

Table 8: Mental workload measures definitions

Measure	Definition
Heart Rate (HR):	This is a mean heart rate value averaged on the entire trial recording. HR is measured in beats per minute (BPM).
Normalised high frequency (HFn):	Normalised High Frequency is the ratio between absolute value of the High Frequency and difference between Total Power and Very Low Frequency.
Normalised low frequency (LFn)	Normalised Low Frequency is the ratio between absolute value of the Low Frequency and difference between Total Power and Very Low Frequency.
Low frequency/high frequency ratio (Lf/Hf):	This is the ratio between the power of Low Frequency and High Frequency bands.

2.1.2.8 Assessment of bowel suturing

Suture execution time: Defined as the interval in seconds from driving the needle through the porcine bowl until the completion of the knot tying. Task performance for each subject under each condition was video recorded for later analysis to obtain the suture execution time.

Suture placement error score: Used as a measure of the accuracy of suture placement. Suture bites had to be 3 to 5 mm from the edge of the enterotomy and 3 to 5 mm apart. The entry and exit points were marked and the distances measured; mm less than 3 and more than 5 were added to produce a suture placement score, the lower the score (mm) the better the suture placement.

2.1.2.9 Knot testing apparatus

The two ends of the divided loop of the knot were inserted between the jaws of the clamps and distracted by Instron tensiometer (Model 1026, Instron, High Wycombe, United Kingdom) (Figure 6). Signals from the load cell were fed to a conditioning unit to modify and filter the signal. The modified signal was recorded by an analog-to-digital conversion card (Advantech PCL-812PG, Roldec System, Wolverhampton, UK) inserted in the computer recording system. A program (Snapshot, HEM Data, Southfield, MI) controlled the conversion card and displayed the load cell waveform. A data analysis program (written in Matlab, The Math Work, Natick, MA) was used to analyze force-extension curves (Figures 7 and 8) (Hanna et al., 1997a).

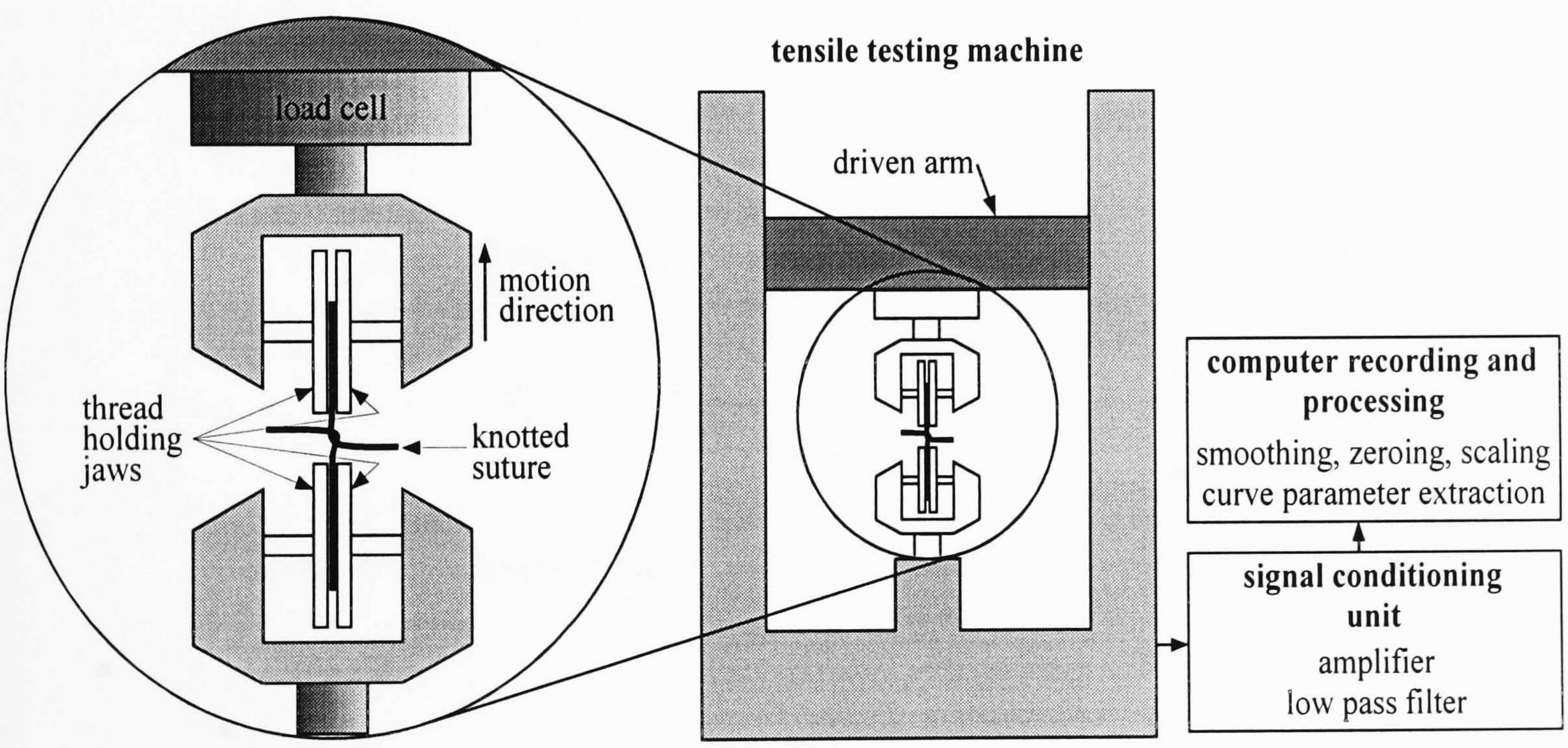

Figure 6: Instron tensiometer

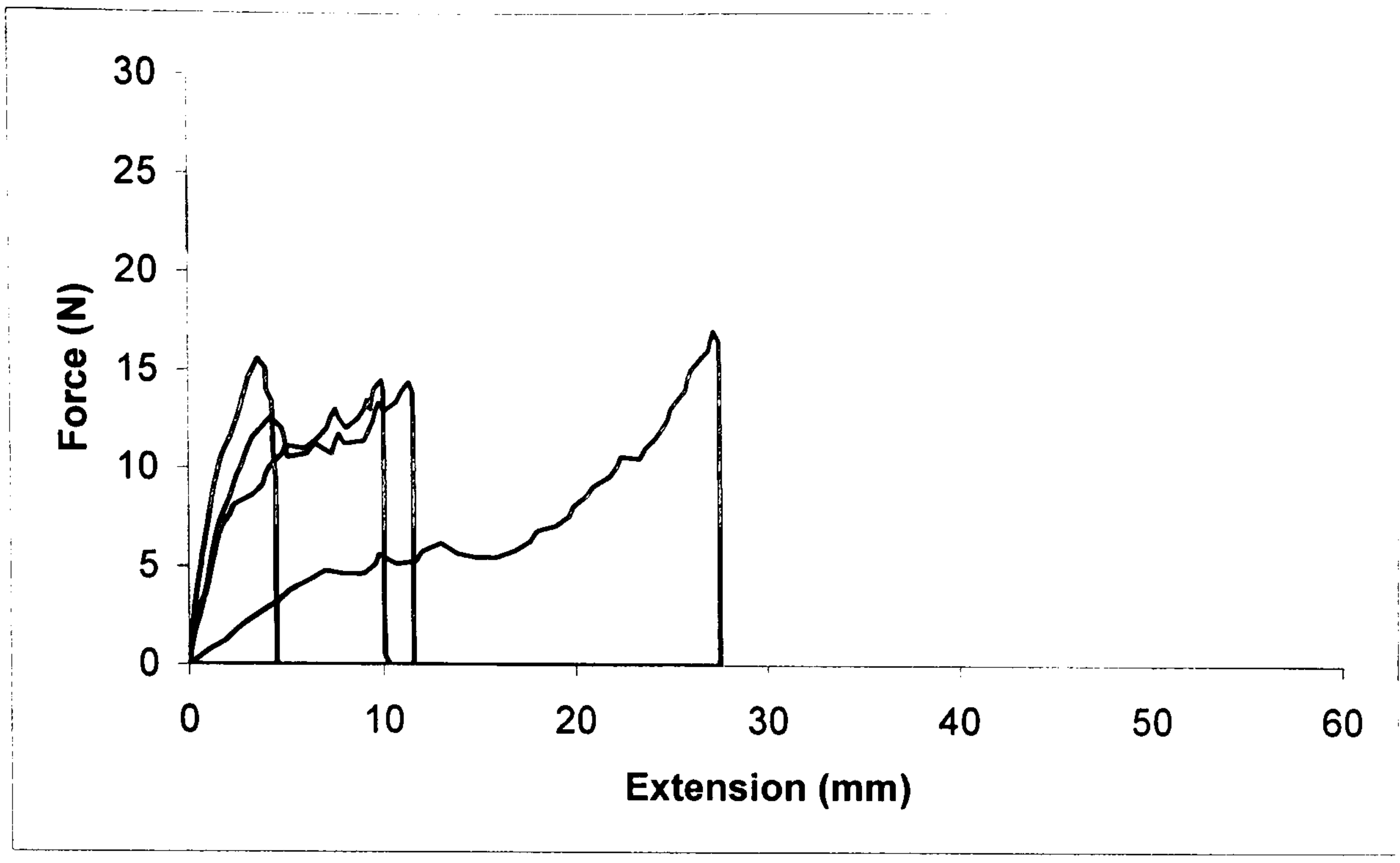

Figure 7: Examples of knots tied with 2/0 silk that break on distraction

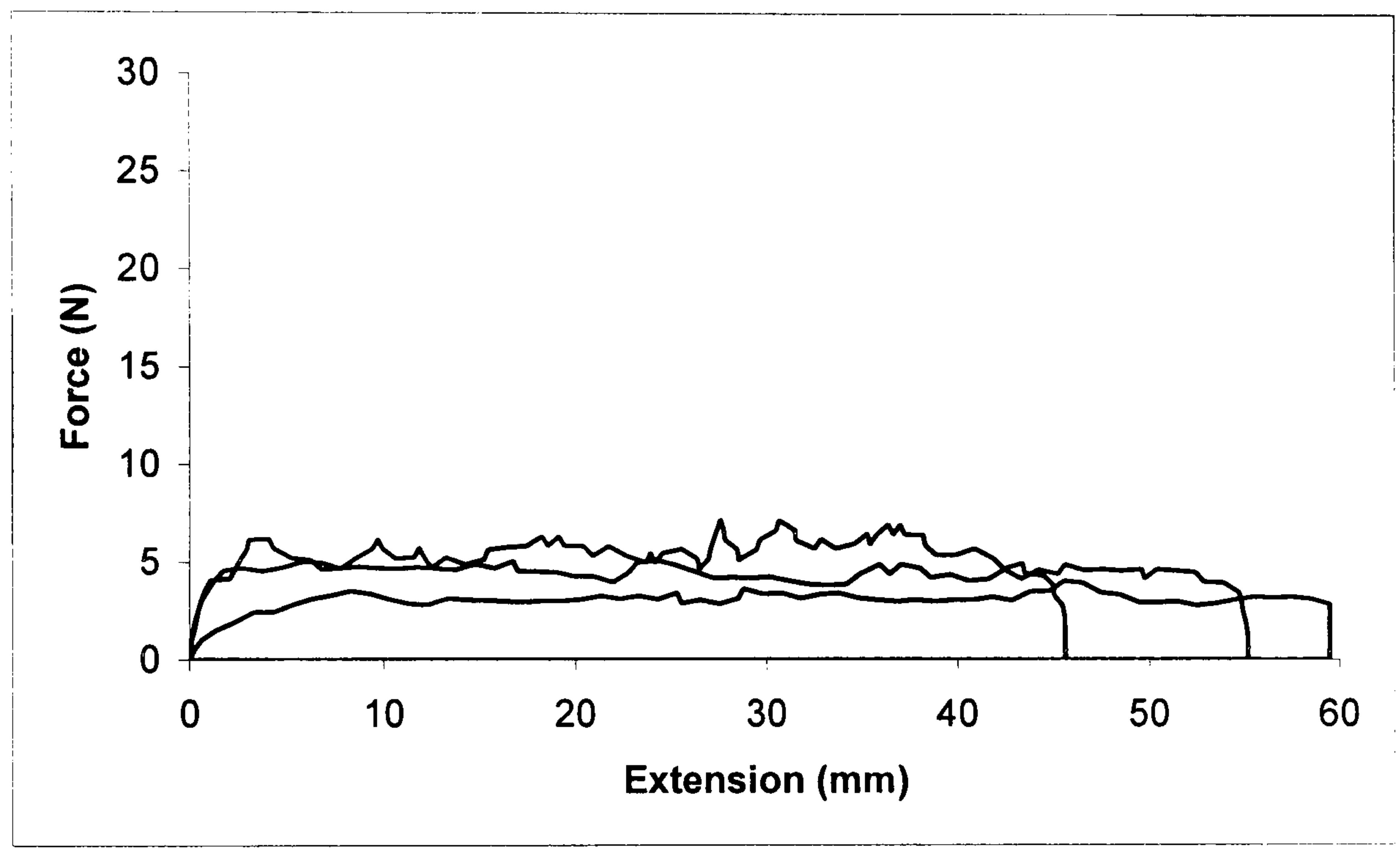

Figure 8: Examples of knots tied with 2/0 silk that slip on distraction

Knot Quality Score: Knot quality score (KQS) was derived by dividing the product of the knot breaking or slipping force and the integrated force for the knot by the product of the thread breaking force and the integrated force for the thread, and multiplying by 100% as follows:

$$\text{KQS} = \frac{\text{knot breaking or slipping force} \times \text{integrated force for the knot}}{\text{thread breaking force} \times \text{integrated force for the thread}} \times 100\%$$

By expressing the breaking forces, slipping forces, and integrated forces as ratios of the values for untied ligatures, the KQS compensates for the breaking force and strength of the thread and has a degree of independence of thread length and jaw creep. The breaking or slipping force reflects the strength of the knot. The maximum force necessary to break the knot was defined as the breaking force; the slipping force required to undo the knot without breakage of the thread was defined as the average force of the plateau of the curve. The integrated force of the initial slope of the curves is an index of knot tightening (Hanna et al., 1997a).

Knot execution time:

Knot execution time was measured from the moment the surgeon grasped the handle of the needle drivers until the instrument were released on completion of the knot.

2.1.2.10 Control measures

The experiment was conducted at 9.00 o'clock in the morning before starting any of the working duties; in the same environment; illumination and under controlled room temperature (using air conditioner with temperature and humidity control and display facility). Surgeon had to have at least 6 hours sleep and not participated in any duty the night before the day of the study.

The experimental setup was standardised by placing the endoscopic trainer on a table of adjustable height so that when the surgeon held the needle drivers with the shoulder adducted, the elbow formed a right angle. The ports for the telescope and the needle drivers were inserted into the trainer to obtain 60° manipulation angle, 60° elevation angle, equal azimuth angles (figure 9) and 10 cm endoscope to task distance (Hanna et al., 1997c).

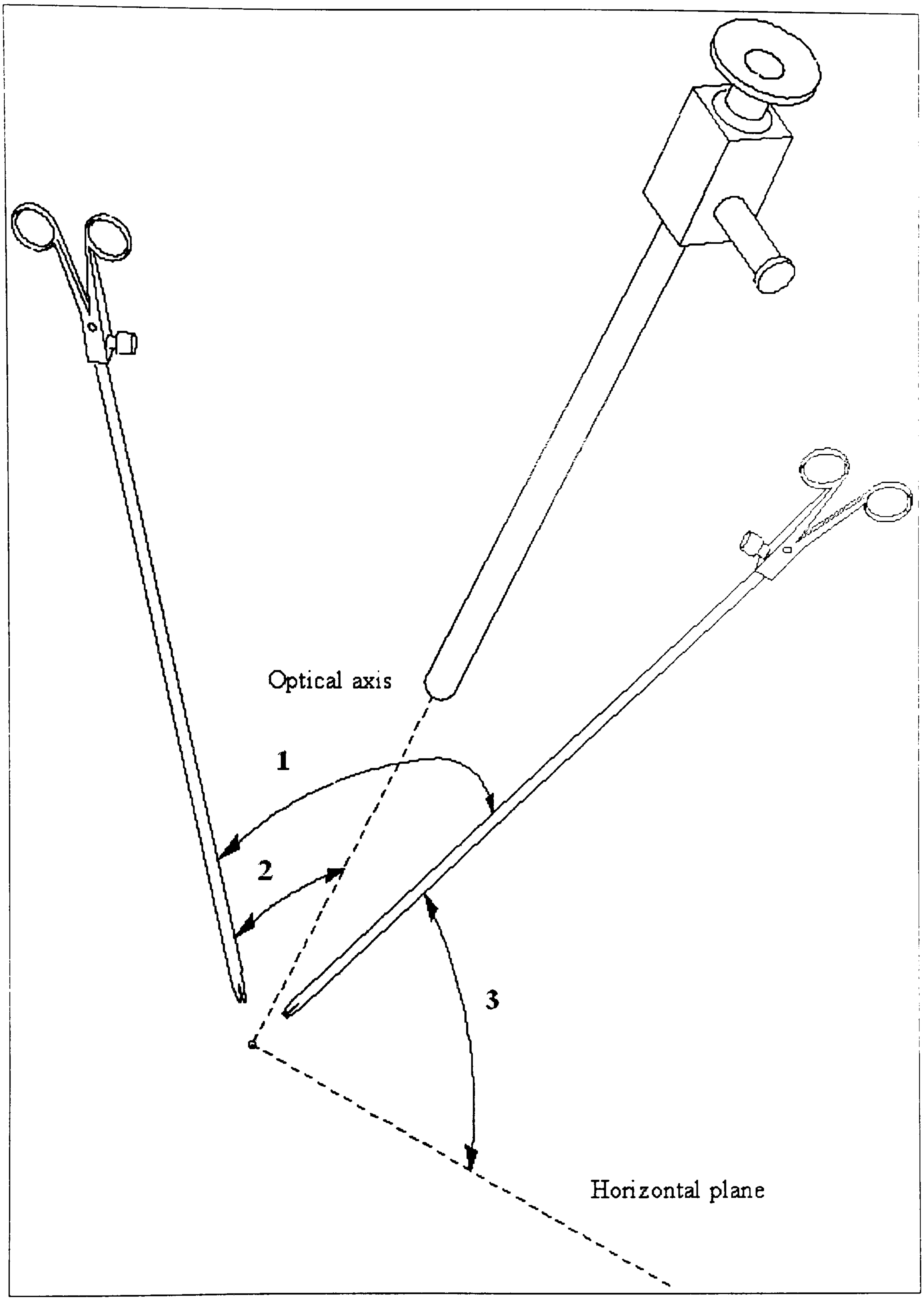

Figure 9: 1-Manipulation angle, 2- Azimuth angle, and 3- Elevation angle

2.1.2.11 Outcome measures

2.1.2.11.1 Posture:

Five postural angles (Table 2) were measured from the video clips:

- Gaze angle (GA);
- Head angle (HA);
- Neck angle relative to the body (NA-b);
- Neck angle relative to the vertical (NA-v);
- Thoracic bending angle (TB).

2.1.2.11.2 Muscle workload

Integrated EMG signals of the following muscles from the right side of the body were used as an index for muscle workload:

- Sternocleidomastoid,
- Trapezius,
- Erector spinae and
- Deltoid muscles.

2.1.2.11.3 Mental workload:

- Heart Rate (HR);
- Normalised low frequency band (Lfn);
- Normalised high frequency band (Hfn); and
- Low frequency/High frequency ratio (Lf/Hf).

2.1.2.11.4 Task performance

- Endoscopic bowel suturing:

  Suture placement error score

  Suture execution time

- Intracorporeal knot tying

  Knot quality score and

  Knot execution time

2.1.2.11.5 Preferences

Subjects were asked about there preference of image size and viewing distance.

2.1.2.12 Physiological data standardisation

Heart rate and heart rate variability data were standardised (Backs et al., 1994; Meijman TF 1997; Vicente et al., 1987). For viewing distance and image size experiment, each subject's log-transformed value during the task was subtracted from his log-transformed one of the average over the baseline and rest periods (Meijman TF 1997). As data were not normally distributed, the data were log-transformed in order to be able to use repeated measures ANOVA to see if there is any interaction between image size and viewing distance. In the gaze down study HR and HRV data were analysed as difference scores from the average over the baseline and rest periods (Backs et al., 1994). The main advantage of this standardisation procedure is that it decreases the inter-individual variability of the raw values of heart rate and heart rate variability components. Electromyogram (EMG) data were not standardised because EMG activity during base line and rest were minimal (Backs et al., 1994).

2.1.2.13 Statistical analysis

As it is difficult to get a large number of volunteer surgeons, Dr. Simon Ogston (Lecturer in Medical Statistics, Department of Epidemiology and Public Health, Ninewells Hospital and Medical School) was consulted regarding the sample size. The reported related research (Berguer et al., 1998; Berguer et al., 2001a; Emam et al., 2001; Uhrich et al., 2002) and the experience of Professor Sir Alfred Cuschieri and Mr. George Hanna was also considered. Furthermore we have performed trial runs to test the system. Depending on all of that an interrupted bowel suturing task was chosen for the study.

Repeated measures ANOVAs (GLM procedure, SPSS) were carried out on standardised mental workload and computed posture data to allow further investigation of interaction between image size and viewing distance. Muscle workload and performance data were not normally distributed even after natural logarithmic transformation; hence nonparametric tests (Friedman's ANOVA and Wilcoxon Signed Ranks Test) were used. The significance level was set at <0.05. Descriptive mental workload and posture data are presented in geometric mean and 95% confidence interval, whereas; muscle workload and performance data are presented in median and interquartile range.

2.1.3 Results

2.1.3.1.1 Posture

2.1.3.1.1.1 Effect of image size and viewing distance on posture

The mean and 95% confidence interval of the postural angles with different viewing distances and monitor sizes are presented in tables 9-13 and illustrated in figures 10-14. Distance did not significant influence thoracic bending angle, neck angle relative to the body, head angle, gaze angle, and neck angle relative to the vertical [F (1, 12) = 0.14, p>0.05], [F (2, 18) = 0.6, p>0.05], [F (1, 10) = 1.68, p>0.05], [F (1, 12) = 0.9, p>0.05], [F (2, 18) = 2.43, p>0.05] respectively.

Monitor size did not significantly affect Tb angle [F (1, 9) = 1.9, p>0.05], Neck-b angle [F (1, 9) = .9, p>0.05], Head angle [F (1, 9) = 0.8, p>0.05], Gaze angle [F (1, 9) = 0.2, p>0.05], and Neck-v angle [F (1, 9) = 0.7, p>0.05].

There was no significant interaction between the distance and size in relation to the postural angles. The main effect for Tb angle was [F (1, 10) = 0.8, p>0.05], Neck-b angle [F (1, 10) = 1.1, p>0.05], Head angle [F (1, 11) = 1.5, p>0.05], Gaze angle [F (2, 18) = 0.3, p>0.05], and Neck-v angle [F (1, 11) = 0.2, p>0.05].

Table 9: Mean and 95% confidence interval (95% CI) of thoracic bending angle angle (degrees) with the used image sizes and viewing distances

Viewing distance	**60 cm**		**100 cm**		**150 cm**	
Image size	**Small image**	**Large image**	**Small image**	**Large image**	**Small image**	**Large image**
Subjects	10	10	10	10	10	10
Mean of the angle (degrees)	139.4	137.5	138.4	135.9	137.7	136.4
Lower 95% CI	135.7	134.3	134.9	132.5	134.3	133.4
Upper 95% CI	143.1	140.6	141.9	139.4	141.0	139.3

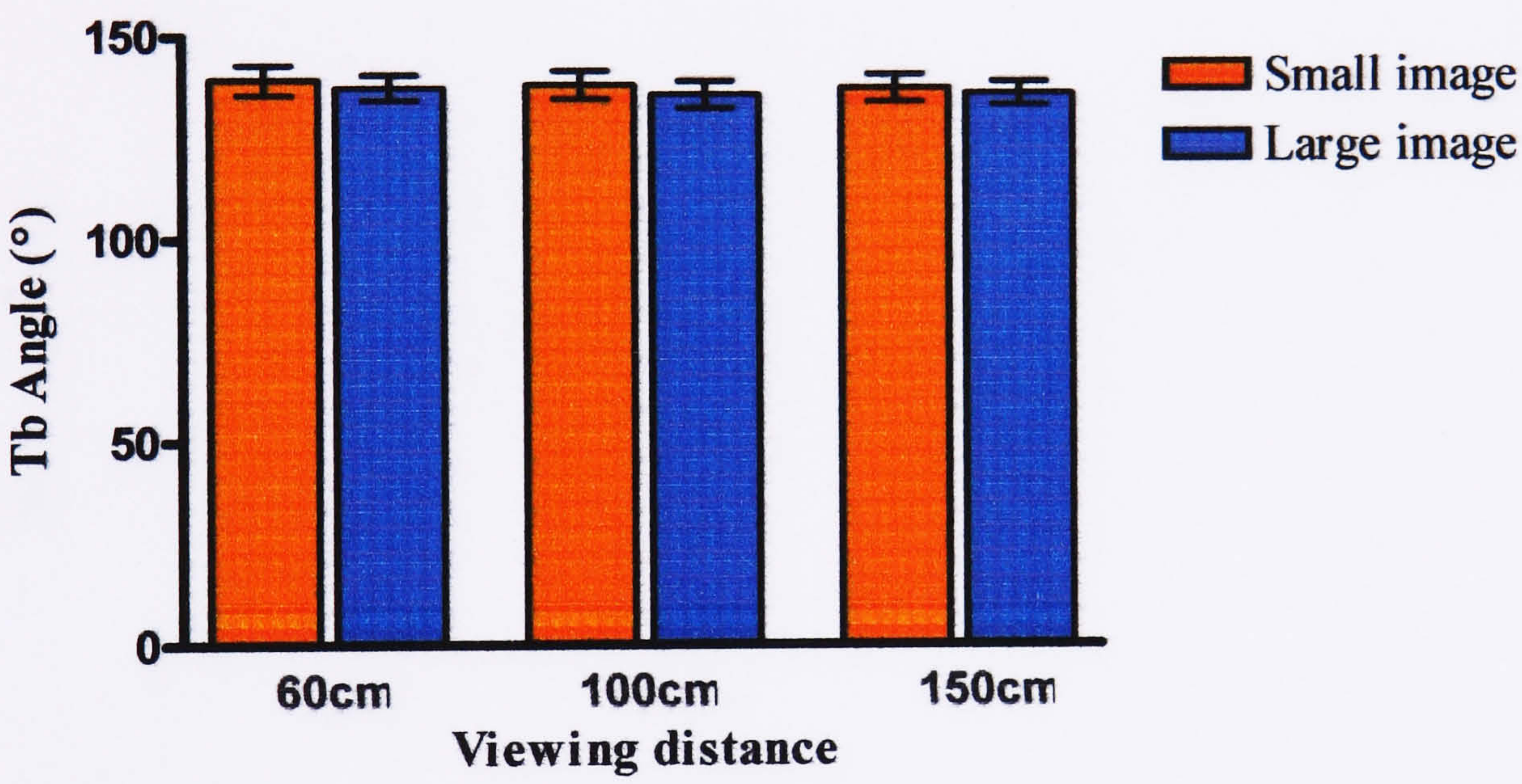

Figure 10: The mean and 95% CI of change in thoracic bending angle with the different image size and location

Table 10: Mean and 95% CI of neck angle relative to the body (degrees) with the used image sizes and viewing distances

Viewing distance	**60 cm**		**100 cm**		**150 cm**	
Image size	**Small image**	**Large image**	**Small image**	**Large image**	**Small image**	**Large image**
Subjects	10	10	10	10	10	10
Mean of the angle (degrees)	132.1	133.7	131.8	131.6	130.4	131.0
Lower 95% CI **Upper 95% CI**	126.5 137.7	129.0 138.4	125.7 137.9	121.9 141.3	123.7 137.0	125.1 136.9

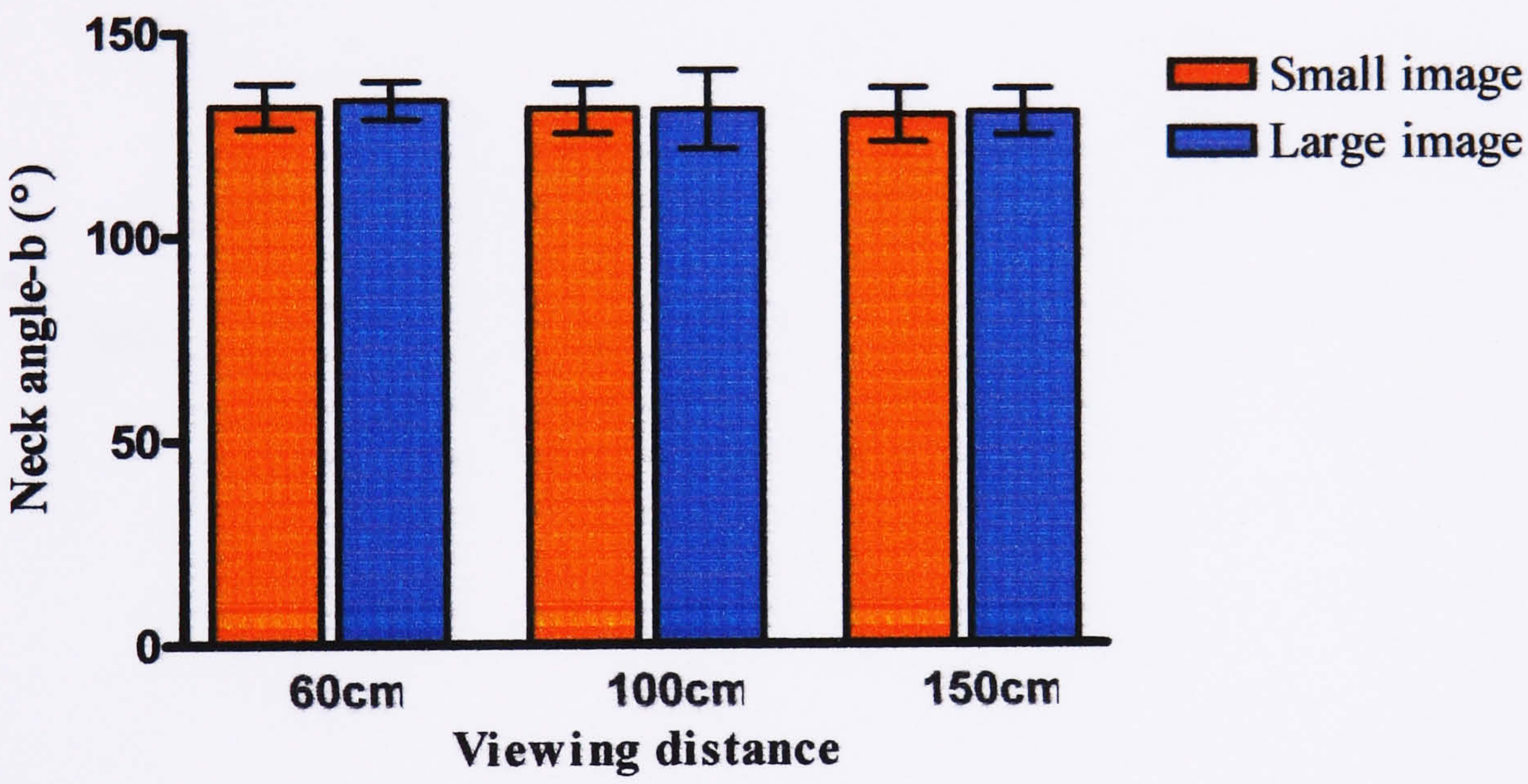

Figure 11: The mean and 95% CI of change in neck angle relative to the body with the different image size and location

Table 11: Mean and 95% CI of head angle (degrees) with the used image sizes and viewing distances

Viewing distance	**60 cm**		**100 cm**		**150 cm**	
Image size	**Small image**	**Large image**	**Small image**	**Large image**	**Small image**	**Large image**
Subjects	10	10	10	10	10	10
Mean of the angle (degrees)	149.3	149.7	153.1	152.6	152.6	154.2
Lower 95% CI **Upper 95% CI**	143.1 155.4	141.2 158.1	144.0 162.3	143.0 162.3	145.6 159.6	147.3 161.2

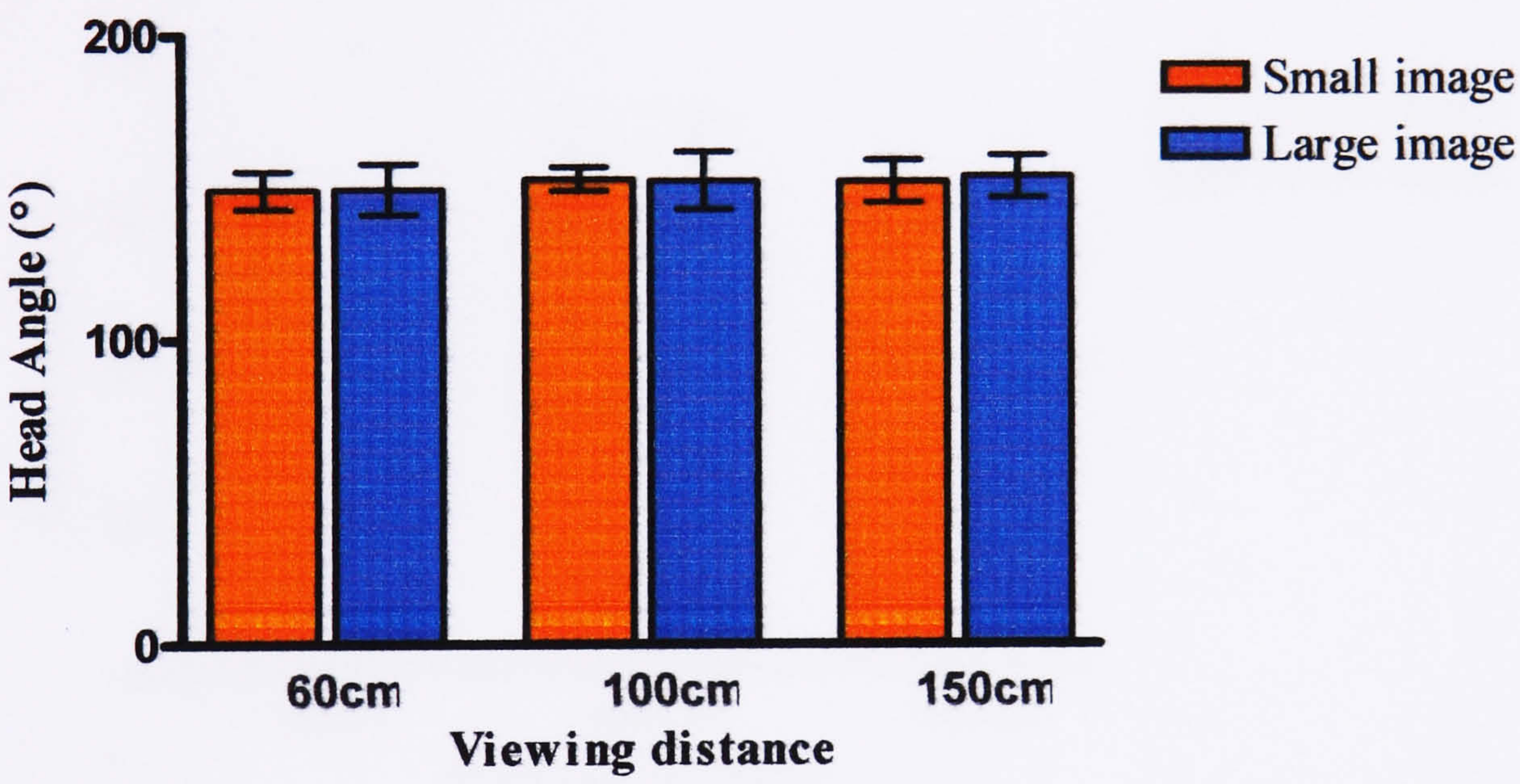

Figure 12: The mean and 95% CI of change in head angle with the different image size and location

Table 12: Mean and 95% CI of gaze angle (degrees) with the used image sizes and viewing distances

Viewing distance	**60 cm**		**100 cm**		**150 cm**	
Image size	**Small image**	**Large image**	**Small image**	**Large image**	**Small image**	**Large image**
Subjects	10	10	10	10	10	10
Mean of the angle (degrees)	26.13	25.52	28.91	28.64	26.17	26.22
Lower 95% CI **Upper 95% CI**	19.99 32.26	19.55 31.49	21.39 36.43	20.84 36.44	20.79 31.55	19.00 33.44

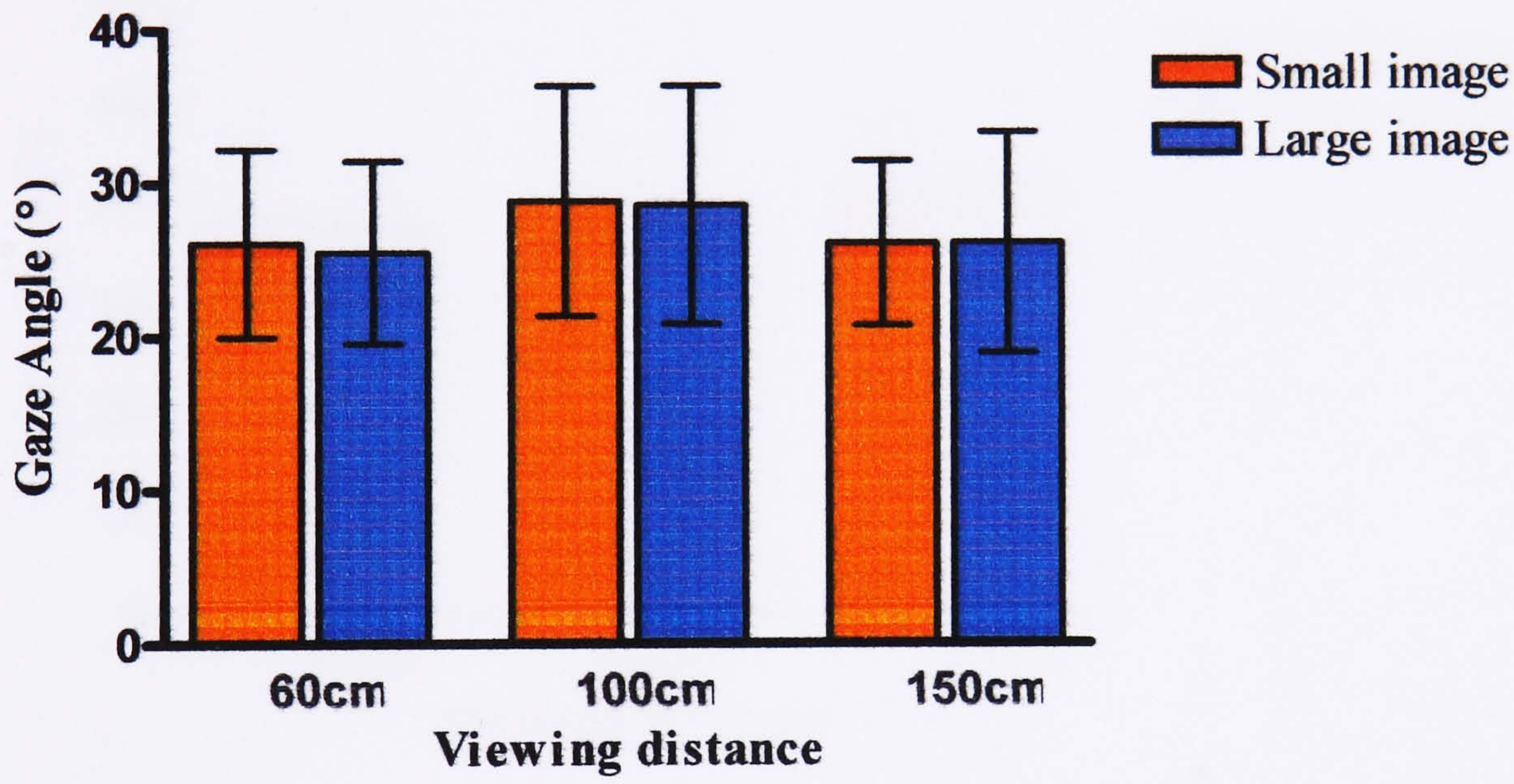

Figure 13: The mean and 95% CI of change in gaze angle with the different image size and location

Table 13: Mean and 95% CI of neck angle relative to the vertical (degrees) with the used image sizes and viewing distances

Viewing distance	60 cm		100 cm		150 cm	
Image size	**Small image**	**Large image**	**Small image**	**Large image**	**Small image**	**Large image**
Subjects	10	10	10	10	10	10
Mean of the angle (degrees)	39.01	38.34	40.49	39.22	41.99	43.14
Lower 95% CI **Upper 95% CI**	32.55 45.47	32.25 44.42	34.09 46.88	27.33 51.11	35.26 48.73	35.12 51.16

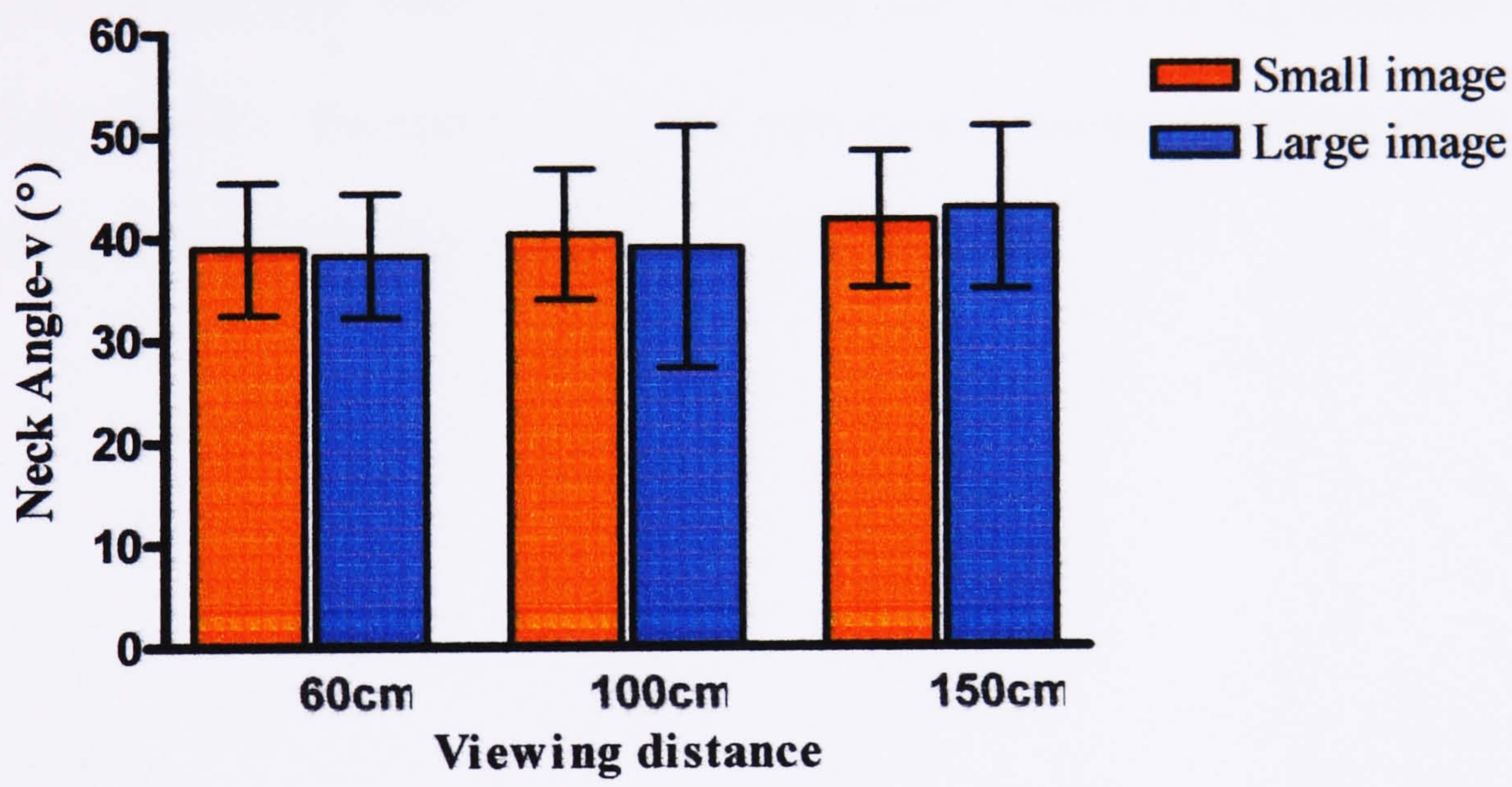

Figure 14: The mean and 95% CI of change in neck angle relative to the vertical with the different image size and location

2.1.3.1.1.2 Effect of time-on task on posture

Table 14 shows the median (interquartile range) of the selected postural angles with Friedman's ANOVA test using small monitor at 60cm, 100cm, and 150cm viewing distances. The results show that there was a significant shift in Thoracic bending (Tb) angle when the small monitor placed at 150 cm viewing distance ($p<0.05$). Thoracic bending angle decreased significantly from the start and middle of session to its end ($p<0.05$-Wilcoxon rank test) (Figure 15). There was a significant difference in Gaze angle (GA) between the start of the session and end of session with the small monitor placed at 100cm (Figure 16). Neck angle relative to the vertical (Neck Angle-v) increased significantly from the start and middle of session to the end of session ($p<0.05$) with the small monitor placed at 100 cm (Figure 17). Friedman's ANOVA test indicated that time-on-task had no significant effect on head angle (HA) and neck angle relative to the body (Neck Angle-b) under the three small monitor conditions.

The median (interquartile range) of the selected postural angles with Friedman's ANOVA test using large monitor at 60cm, 100cm, and 150cm viewing distances are presented in table 15. The results show that time-on-task has no significant effect on all the selected postural angles with large monitor ($p>0.05$).

Table 14: Effect of time-on-task on median (IQR) postural angles (degrees) for the 10 subjects with small image

	Viewing distance & 5 minutes periods of time								
	60cm			100cm			150cm		
Angle	**1st**	**3rd**	**6th**	**1st**	**3rd**	**6th**	**1st**	**3rd**	**6th**
Tb	139 (5.7)	136 (9.4)	138 (9.7)	138 (7.8)	138 (6.9)	140 (8.0)	140 (0.2)	140 (0.2)	141 (0.1)
P value	**0.89**			**0.64**			**0.00**		
Neck-b	134 (8.2)	135 (7.4)	135 (5)	136 (8.5)	135 (8.3)	132 (5.8)	131 (6.9)	130 (10)	133 (14)
P value	**0.72**			**0.06**			**0.88**		
HA	150 (12)	148 (15)	147 (8.4)	152 (22)	152 (34)	149 (14)	151 (11)	153 (15)	155 (13)
P value	**0.12**			**0.72**			**0.42**		
GA	26 (9.4)	22 (15)	26 (13)	31 (15)	29 (19)	22 (14)	22 (12)	23 (10)	25 (13)
P value	**0.72**			**0.02**			**0.61**		
Neck -v	35 (10)	36 (6.2)	36 (7.0)	36 (9.7)	37 (12)	41 (11)	41 (10)	42 (10)	41 (17)
P value	**0.46**			**0.00**			**0.42**		

P (According to Friedman's ANOVA test)

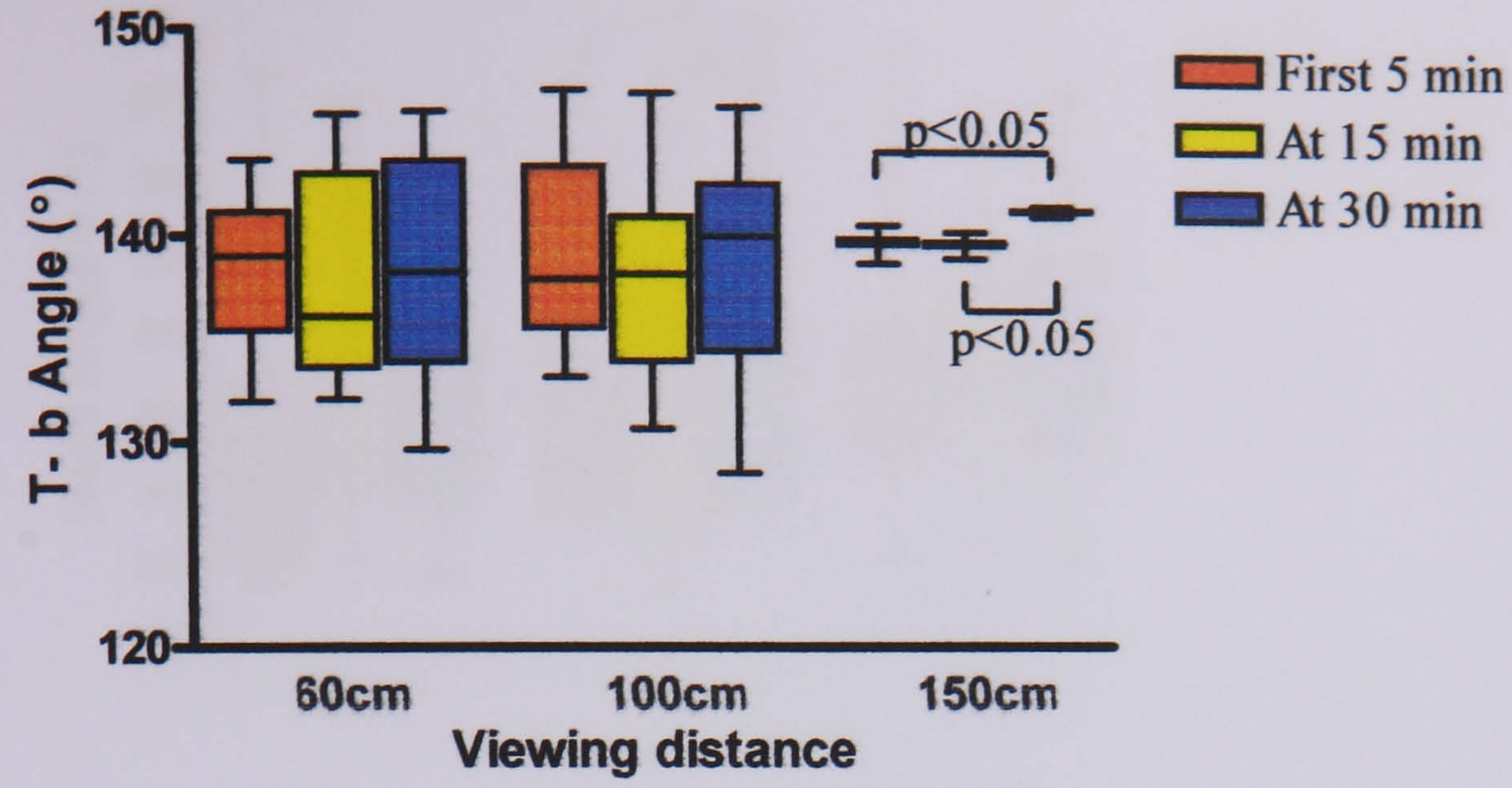

Figure 15: Effect of time-on-task on thoracic bending angle with small monitor

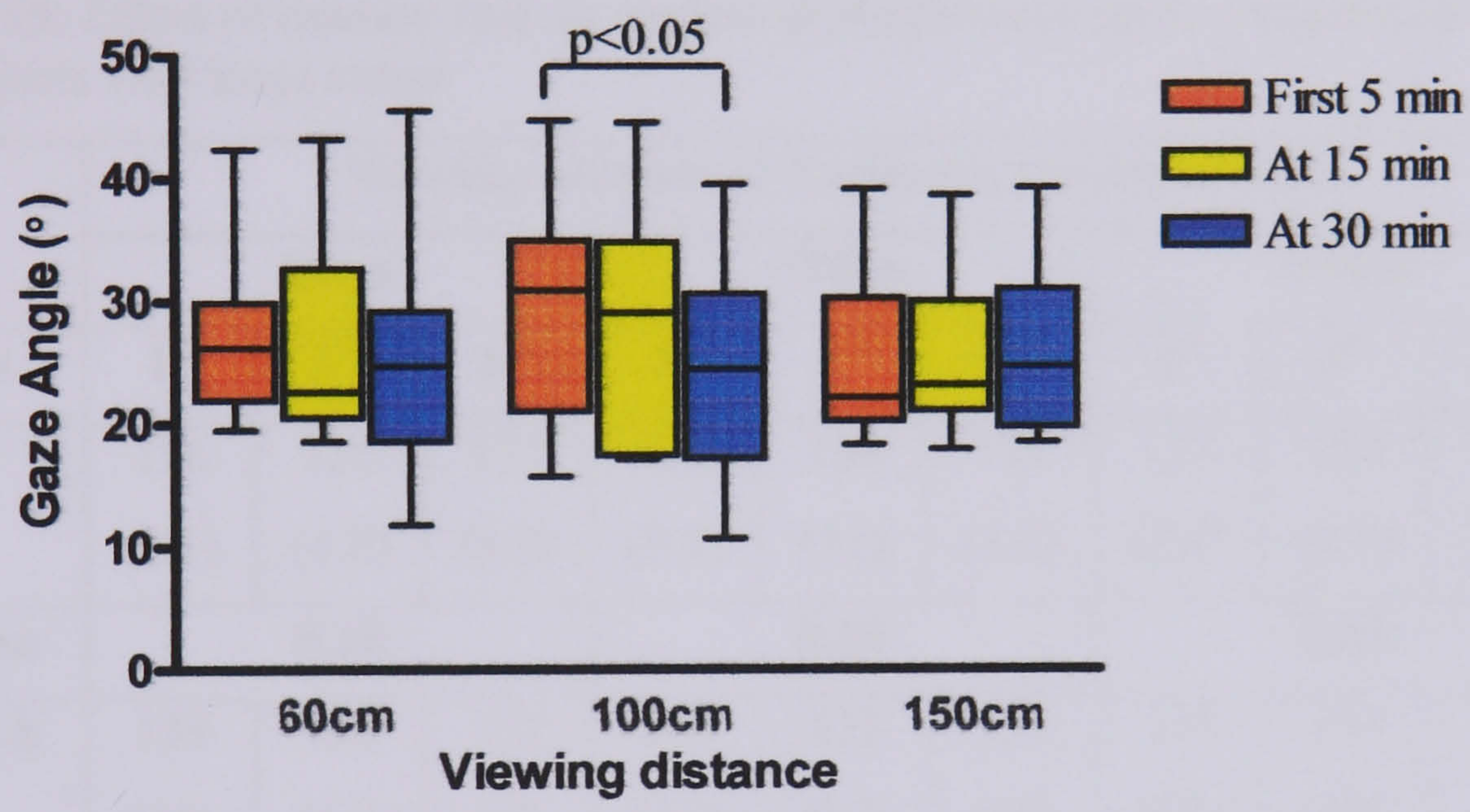

Figure 16: Effect of time-on-task on gaze angle with small monitor.

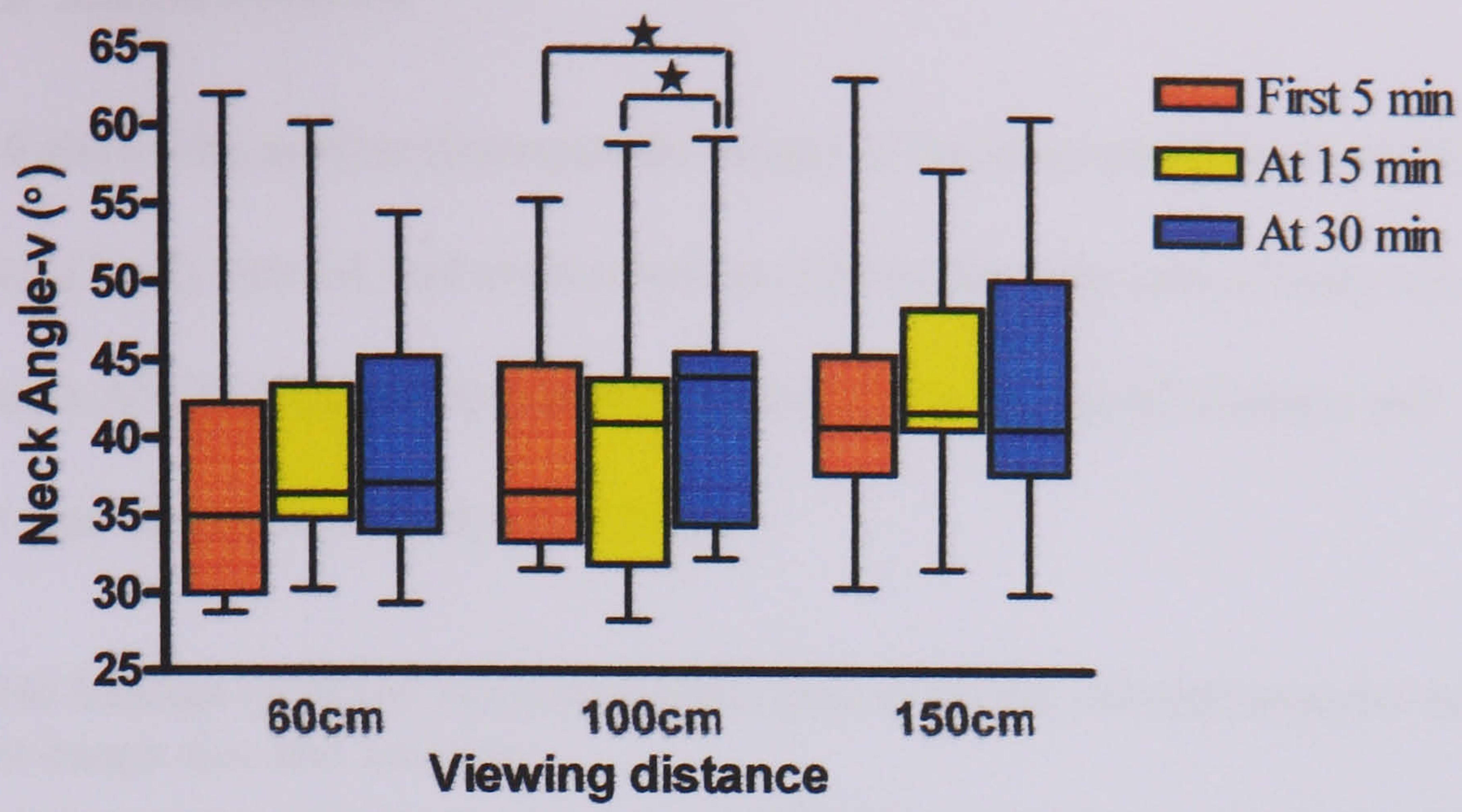

Figure 17: Effect of time-on-task on neck angle relative to the vertical with small monitor. *p<0.05

Table 15: Effect of time-on-task on median (IQR) postural angles (degrees) for the 10 subjects with large image

	Viewing distance & 5 minutes periods of time								
	60cm			100cm			150cm		
Angle	**1st**	**3rd**	**6th**	**1st**	**3rd**	**6th**	**1st**	**3rd**	**6th**
Tb	136 (3.1)	135 (4.8)	135 (4.9)	135 (5.8)	134 (11)	135 (3.2)	137 (3.4)	134 (5.6)	137 (9.5)
P value	**0.29**			**0.88**			**0.65**		
Neck-b	138 (11)	135 (12)	132 (9)	134 (17)	133 (15)	134 (18)	133 (11)	131 (11)	133 (12)
P value	**0.37**			**0.07**			**0.69**		
HA	150 (23)	144 (20)	147 (29)	156 (25)	158 (15)	153 (24)	149 (9)	148 (10)	158 (12)
P value	**0.05**			**0.88**			**0.16**		
GA	27 (9.1)	27 (17)	27 (18)	28 (15)	29 (16)	31 (18)	25 (17)	23 (19)	26 (16)
P value	**0.46**			**0.88**			**0.42**		
Neck -v	38 (12)	37 (10)	36 (10)	39.2 (17)	37.1 (19)	38 (22)	39 (15)	42 (15)	40.3 (18)
P value	**0.64**			**0.88**			**0.19**		

P (According to Friedman's ANOVA test)

2.1.3.1.2 Muscle workload

Table 16 shows the median (interquartile range) of the sternocleidomastoid (SCM), Trapezius (Trap), deltoid, and erector spinae (ES) of the right side of body with Friedman's ANOVA test. There was no significant influence of distance and monitor size on muscle activity (p>0.05).

Table 16: Median (IQR) of integrated EMG (mv.s) for the selected muscles with different image size and location

	Distance & Size							
		60cm		100cm		150cm		
Muscle	**Subjects**	**Small**	**Large**	**Small**	**Large**	**Small**	**Large**	**p**
SCM	10	7.25 (0.31)	7.25 (0.33)	7.22 (3.56)	7.22 (0.04)	7.25 (0.32)	7.22 (3.51)	0.57
Trap	10	6.77 (0.41)	6.77 (0.81)	6.77 (2.75)	6.77 (.00)	6.77 (0.41)	6.77 (3.53)	0.49
Deltoid	10	0.75 (0.18)	0.77 (0.12)	0.75 (0.53)	0.76 (0.07)	0.75 (0.10)	0.75 (0.51)	0.22
ES	10	3.16 (0.03)	3.16 (2.87)	3.16 (0.07)	3.16 (0.57)	3.16 (0.57)	3.16 (2.07)	0.23

P (according to Friedman's ANOVA test)

2.1.3.1.3 Mental workload

Mean increase in HR (beats/min) under each level of independent variables are shown in table 17 and figure 18, in terms of changes from the baseline period for each independent variable. The mean increase in heart rate (beats/min) was 10.54, 5.16, and 8.36 for the small monitor at 60cm, 100cm, and 150cm viewing distances respectively, whereas; the increase in the heart rate (beats/min) from the baseline period for the large monitor was 7.75, 5.71, 10.07 at 60cm, 100cm, and 150cm viewing distances respectively.

Viewing distance did not significantly affect HR [*F* (2, 18) = 1.92, p>0.05]. Image size has no significant effect on HR [F (1, 9) = 1.92, p>0.05]. Heart rate data showed no significant interaction between size and distance [F (2, 18) = 1.68, p>0.05].

Table 17: The mean and 95% CI of increase in heart rate (beats/min) with the different image size and location, in terms of change from the baseline period for each condition

Viewing distance	**60 cm**		**100 cm**		**150 cm**	
Image size	**Small image**	**Large image**	**Small image**	**Large image**	**Small image**	**Large image**
Subjects	10	10	10	10	10	10
Mean heart rate (Beats/min)	10.54	7.754	5.164	5.713	8.359	10.07
Lower 95% CI	2.23	1.95	2.17	3.12	0.21	0.37
Upper 95% CI	18.85	13.56	12.49	14.55	16.93	19.77

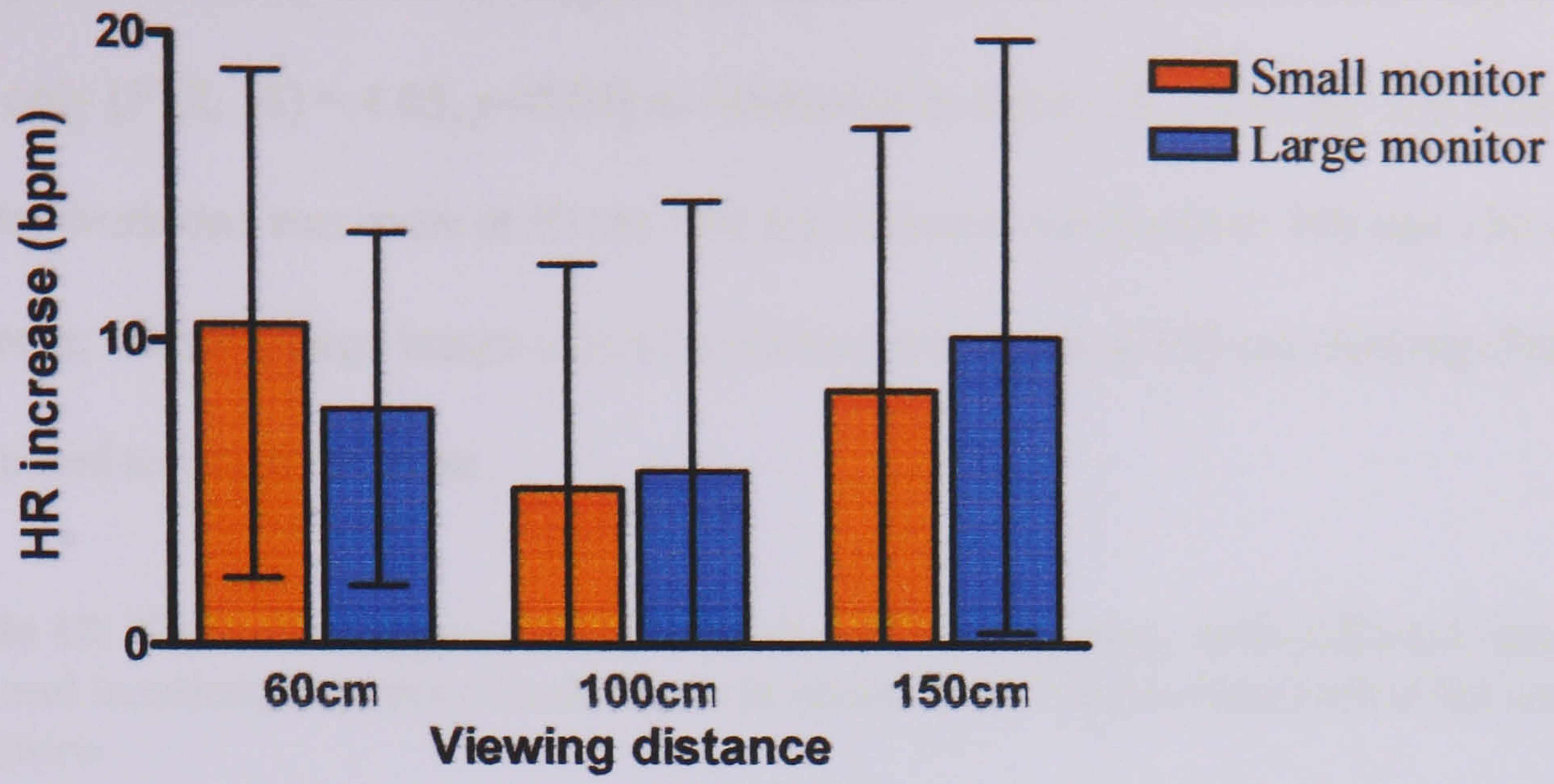

Figure 18: The mean and 95% CI of increase in HR (bpm = beats/min) with the different image size and location, in terms of changes from the baseline period for each condition

Analysis of variance for heart rate variability data revealed a significant affect of viewing distance on LFn [F (2, 18) = 3.69, p<0.05] but not HFn [F (2, 18) = 0.23, p>0.05] or LF/HF [F (2, 18) = 10.5, p>0.05]. Paired samples t-test (with Bonferroni correction) showed that the mean LFn was significantly suppressed from the baseline period with the small monitor at 60cm (-11.98) than (-2.144) at 100cm and (-4.11) at 150cm (Figure 19). However; the change in distance did not significantly affect the LFn with the large monitor (p>0.05).

Analysis of variance for heart rate variability data showed a significant affect of image size on LFn [F (1, 9) = 8.60, p<0.05], HFn [F (1, 9) = 5.95, p<0.05] and LF/HF [F (1, 9) = 13.62, p<0.05]. Paired samples t-test (with Bonferroni correction) indicated that monitor size has a significant affect on LFn at 60cm viewing distance but not at 100cm or 150cm viewing distances (Table 18 and figure 19). LFn was significantly suppressed from the baseline period with the small monitor at 60cm (-11.98) compared to (-1.874) for the large monitor at the same distance (p<0.05).

Analysis of variance showed a significant interaction between the distance and size in LFn only [F (2, 18) = 4.05, p<0.05] as illustrated in figure 20. With the small image mental workload was more at 60 cm viewing distance compared to 100 and 150 cm, whereas; with the large image mental workload was more at 150 cm viewing distance compared to 60 and 100 cm.

Table 18: The mean suppression of normalised low frequency with different image size and location, in terms of reductions in power from the baseline period for each condition

Viewing distance	**60 cm**		**100 cm**		**150 cm**	
Image size	**Small image**	**Large image**	**Small image**	**Large image**	**Small image**	**Large image**
Subjects	10	10	10	10	10	10
Normalised low frequency (Arbitrary units)	-11.98	-1.87	-2.14	-1.13	-4.11	-4.36
Lower 95% CI **Upper 95% CI**	-18.48 -5.49	-10.11 6.37	-6.84 2.55	-6.68 4.41	-12.36 4.14	-13.07 4.34

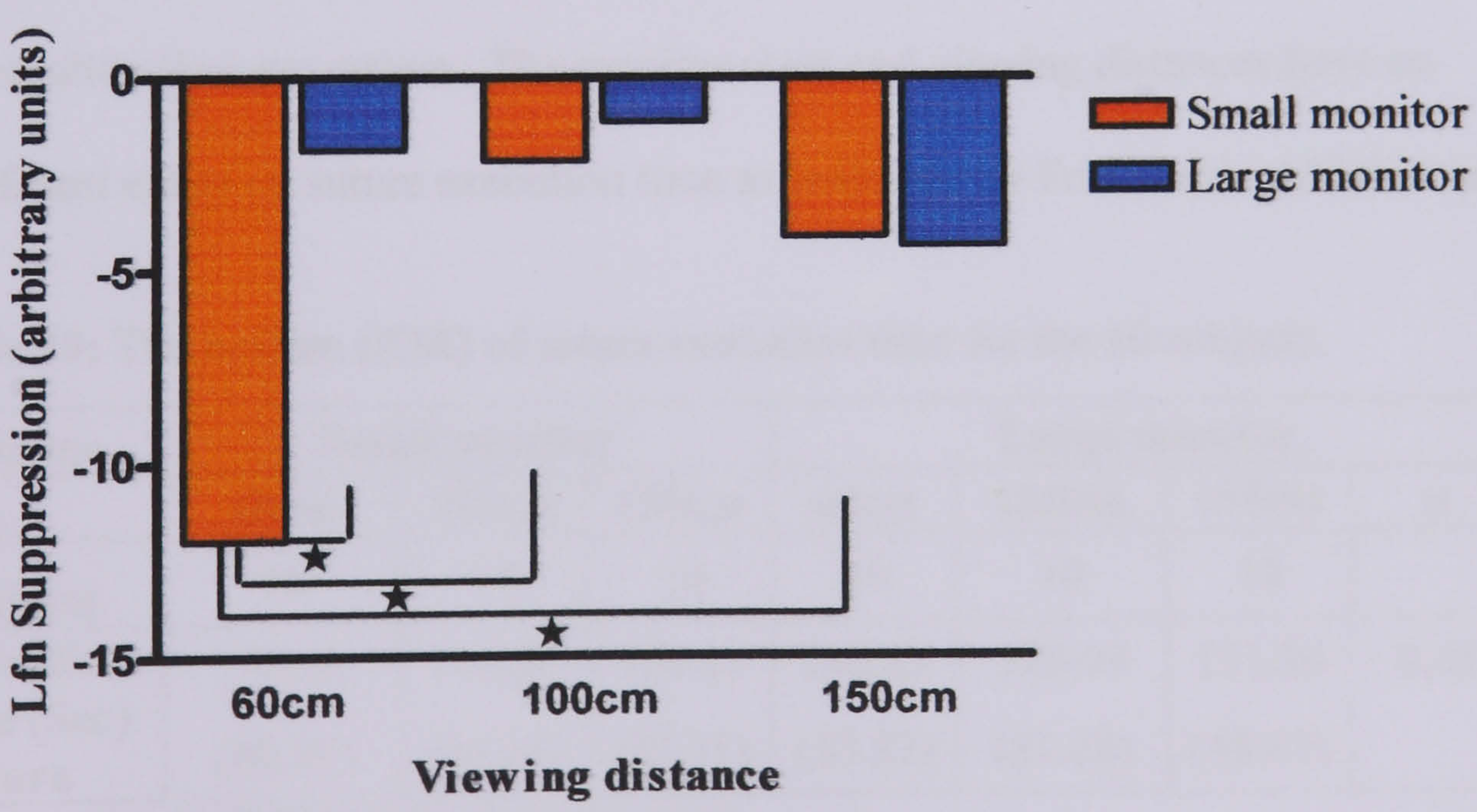

Figure 19: The mean suppression of Lfn with the different image size and location, in terms of reductions in power from the baseline period of each condition, *p<0.05

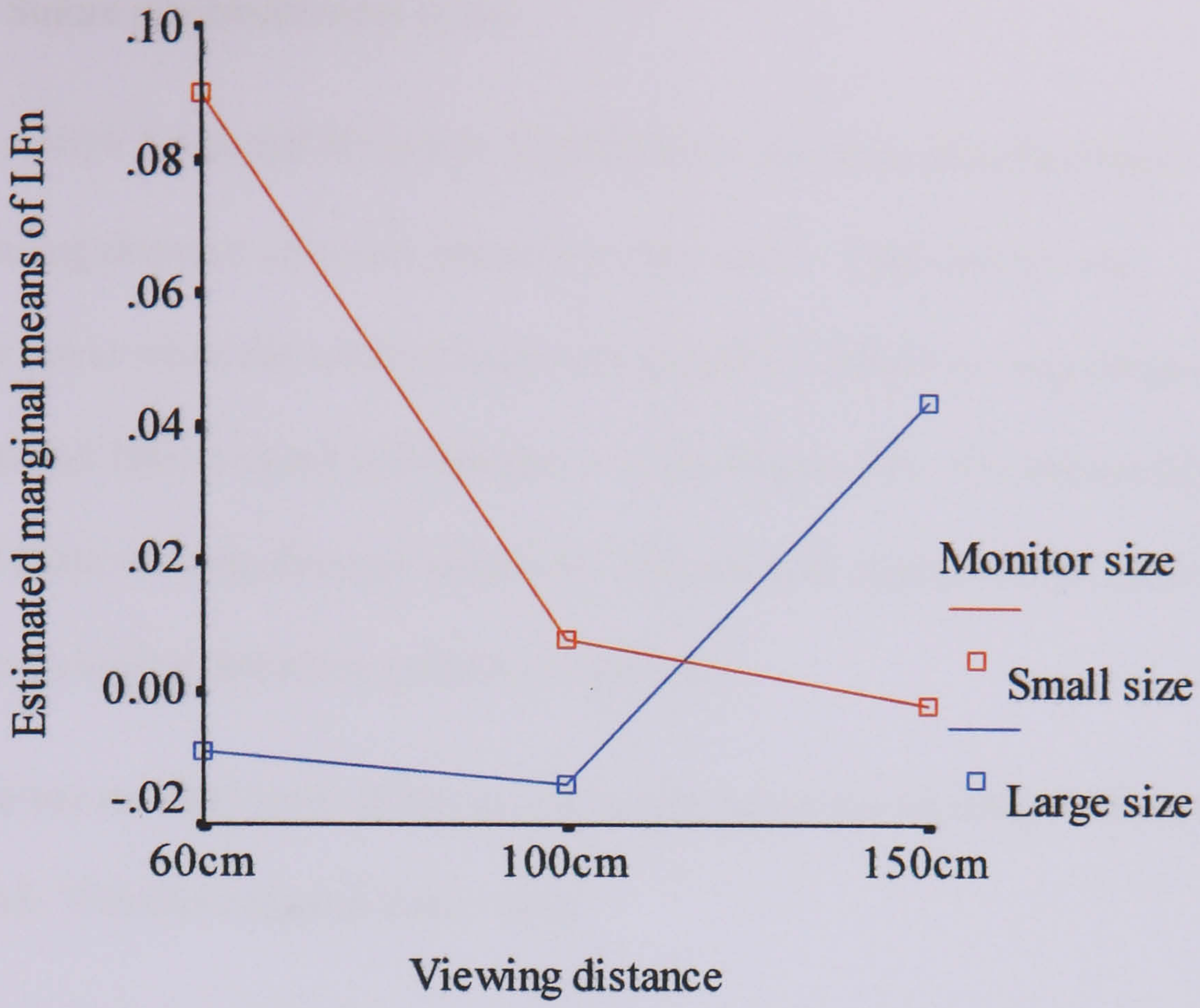

Figure 20: The interaction between image size and viewing distance

2.1.3.1.4 Task performance

2.1.3.1.4.1 Suture execution time

Table 19 presents the median, interquartile range (IQR) and Friedman's ANOVA test of execution time per suture. The monitor sizes and viewing distances have no significant effect on suture execution time as indicated by Friedman's ANOVA test.

Table 19: The median (IQR) of suture execution time for the 10 subjects

Distance	**Small monitor**			**Large monitor**			
Size	**60cm**	**100cm**	**150cm**	**60cm**	**100cm**	**150cm**	p
Subjects	10	10	10	10	10	10	
Execution time (Sec) **/suture**	136.00 (80.85)	118.85 (50.08)	114.47 (30.31)	140.82 (55.83)	140.99 (81.28)	131.86 (48.47)	0.45

P (According to Friedman's ANOVA test)

2.1.3.1.4.2 Suture placement error score

Friedman's ANOVA test and Wilcoxon Signed Ranks test showed a significant effect of viewing distance on suture placement error score. Task quality was significantly lower when the small monitor was placed at 150cm viewing distance than at 60cm and 100cm viewing distances ($p<0.05$) (Figure 21). Placing the large monitor at 150cm viewing distance negatively affected task quality compared to 60 cm and100cm viewing distances ($p<0.05$) (Figure 21).

Monitor size has no significant effect on task quality when the viewing distance was fixed ($p>0.05$- Wilcoxon Signed Ranks test).

Table 20: Median (IQR) of suture placement error score for each viewing distance and image size

Distance	Small monitor			Large monitor		
Size	60cm	100cm	150cm	60cm	100cm	150cm
Subjects	10	10	10	10	10	10
Suture placement score (mm)	20.50 (16.8-29.5)	19.50 (15.3-23.5)	19.50 (13.5-34.3)	17.25 (16-25.5)	34.50 (18.5-53.5)	29.00 (16-37.8)

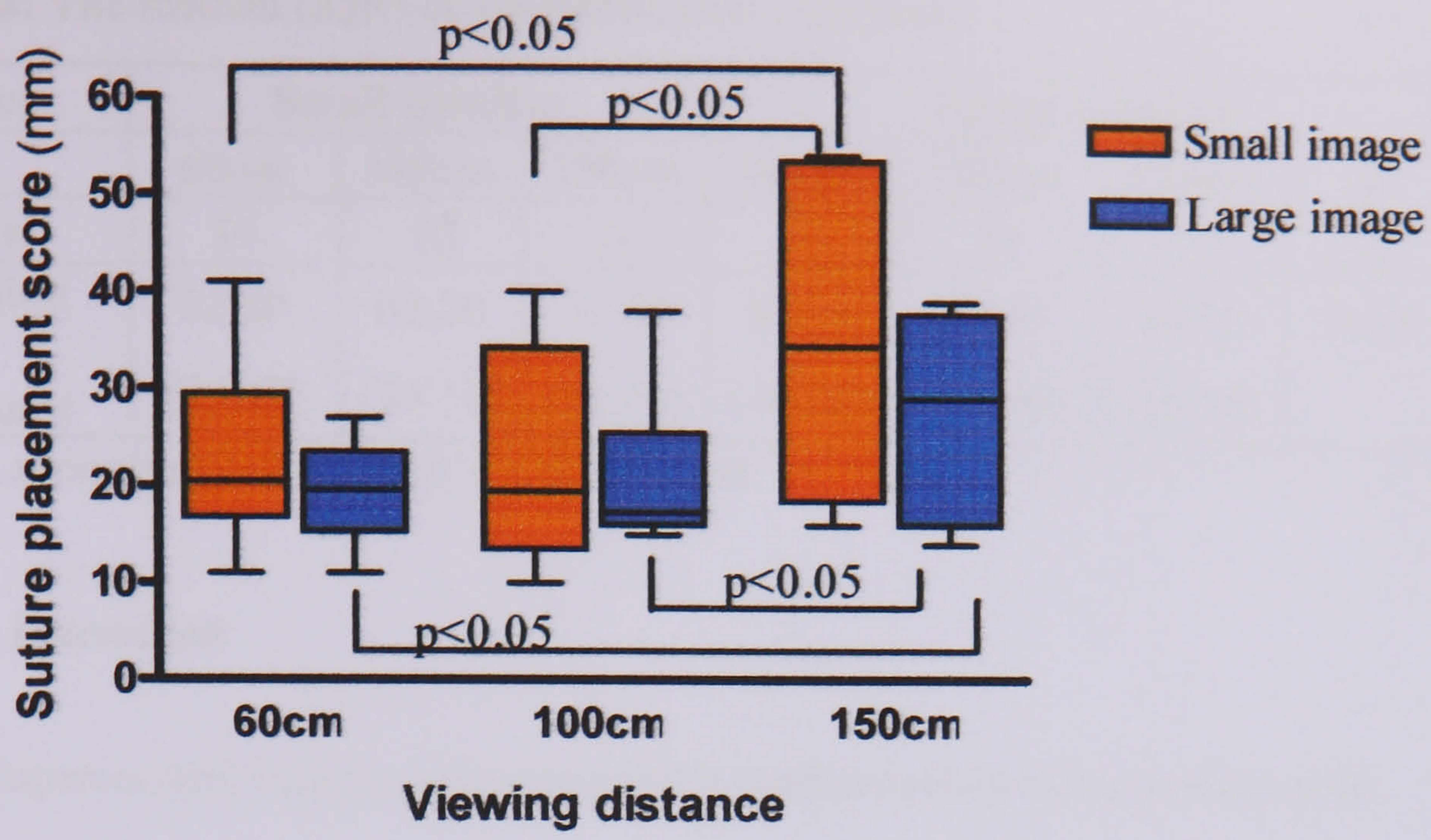

Figure 21: The effect of viewing distance on suture placement error score (mm)

2.1.3.1.4.3 Knot quality score

The used image sizes and viewing distances have no significant effect on knot quality score as shown in table 21.

Table 21: The median (IQR) of knot quality score

Distance	**Small monitor**			**Large monitor**			
Size	**60cm**	**100cm**	**150cm**	**60cm**	**100cm**	**150cm**	**p**
Subjects	10	10	10	10	10	10	
KQS %	20.44 (3.14)	21.02 (16.16)	26.65 (36.35)	20.63 (23.36)	22.48 (10.18)	22.44 (3.14)	0.09

P value, according to Friedman's ANOVA test

2.1.3.1.4.4 Knot execution time

The used image sizes and viewing distances have no significant effect on knot execution time as shown in table 22.

Table 22: The median (IQR) of knot execution time (Sec)

Distance	Small monitor			Large monitor			
Size	**60cm**	**100cm**	**150cm**	**60cm**	**100cm**	**150cm**	p
Subjects	10	10	10	10	10	10	10
Execution time (Sec)/knot	62.80 (39.40)	63.20 (23.10)	75.63 (51.60)	80.20 (46.90)	55.67 (57.00)	80.00 (29.78)	0.33

P value, according to Friedman's ANOVA test

2.1.3.2 Discussion

During laparoscopic surgery surgeons exhibit predominately static posture with upright head and back positions and less weight shifting which can induce fatigue (Berguer et al., 1997). This restricted posture is due to the arrangement of the laparoscopic equipment in the operating room. Monitor position is an important factor for surgeons' axial skeletal posture during laparoscopic surgery. The results showed that displayed image size and viewing distance has no effect on surgeon's posture. However; over time surgeons bent toward the monitor and decreased the viewing distance when the small monitor was placed at 150 cm in order to maintain their performance. Surgeons changed their posture at the level of atlanto-occipital joint over time when the small monitor was placed at 100 cm viewing distance. Placing the small monitor at 60 cm did not affect surgeon's posture. Surgeons' posture did not change over time with the large monitor at all selected viewing distances. Viewing distance and monitor size has no effect on the Sternocleidomastoid, trapezius, deltoid, and erector spinae muscles for performance of short duration task.

Viewing distance influenced surgeons' mental workload (more suppression of Lfn) for the small displayed image but not for the large image. Placing the small monitor at 60cm viewing distance made the surgeon work with high mental effort in order to maintain the same level of performance as at 100cm viewing distance. This can be physiologically reasonable since the accommodation and convergence systems of the eyes have their average resting position at 100cm and any shortening of the viewing distance relative to this resting position increase the load on the ocular muscles and may contribute to eyestrain (Jaschinski-Kruza 1988; Jaschinski-Kruza 1991). On the other hand; placing the small monitor beyond the eye resting position made the surgeons work with a low level of attentional effort and arousal as indicated by their low mental workload and the decline in their performance. This is also applicable for the large monitor when placed at 150cm viewing distance.

Studies on the potential of audio-visual media to provide viewers with an accurate representation of no mediated experience reported that subjects watching larger television screens reported more positive emotional response to the viewing environment and selected a viewing position that represented a smaller withdrawal from the encounter compared to small screens (Lombard 1995). Therefore, surgeons worked with high mental workload when the small monitor was placed at 60cm viewing distance in order to make their performance comparable with the large monitor condition at the same distance. At the eye resting position the image size did not influence the surgeons' mental workload. Therefore surgeons worked with the same level of mental workload and performance under both image sizes. Surgeons worked with significant decline in their performance when small and large monitor was placed beyond the eye resting position. This can explain why image size did not affect mental workload at this distance.

Viewing distance and image size have no significant effect on task execution time. However; task quality was negatively affected with the monitor at 150cm viewing distance as indicated by high suture placement error score. These finding suggest that laparoscopic task performance is diminished with the image displayed beyond the eye resting position.

Subjects were asked about there preference of image size and viewing distance. All subjects preferred large monitor to the small monitor, and they preferred 100 cm viewing distance to the 60 cm and 150 cm.

2.1.3.3 Limitations

Methodological limitations associated with this study include:

- The probability of picking up electrical signals from the adjacent muscle groups (cross talk);
- The use of rest integrated electromyogram data as a reference point;
- Similar to the body of related research, this study was limited by the a small number of participants (surgeons) (Berguer et al., 1998; Berguer et al., 2001a; Emam et al., 2001; Uhrich et al., 2002);
- The use of two image sizes 14 inch and 20 inch only;
- This study was conducted in a controlled environment. In reality, interpretation of surgical images and performance of operations take place in a wide variety of environments, with differing levels of noise, light, and equipment quality. The decision to perform the study in a controlled environment was made in an effort to ensure that differences in results could be attributed to experimental factors.

2.1.3.4 Conclusions

- Viewing distance and image size did not affect postural angles (thoracic bending angle, neck angle relative to the body, head angle, gaze angle, and neck angle relative to the vertical).

- There was no significant interaction between the distance and size in relation to the postural angles.
- Time-on-task caused a significant shift in Thoracic bending angle with 14 inch (small) image at 150 cm, and Gaze angle and Neck angle relative to the vertical at 100 cm. Head angle (HA) and neck angle relative to the body (Neck-b) did not change with time-on-task.
- Time-on-task has no significant effect on all postural angles with 20 inch (large) image at 60 cm, 100 cm, and 150 cm viewing distances.
- Viewing distance and image size have no effect on Sternocleidomastoid, Trapezius, Deltoid, and Latissimus Dorsie, and deltoid muscles activity.
- Viewing distance and image size did not affect surgeons' heart rate.
- There was a significant suppression in the low frequency band (Lfn) of heart rate variability with small image at 60 cm viewing distance compared to 100 cm and 150 cm. Also there was a significant suppression in Lfn with small image at 60 cm compared to large image at the same viewing distance.
- Heart rate variability (Lfn) showed an interaction between image size and viewing distance.
- Image size and viewing distance have no significant effect on task efficiency.
- Task quality was significantly lower when the 14 inch (small) or 20 inch (large) image was placed at 150cm viewing distance compared to 60cm and 100cm.

In summary:

20 inch (large) image was superior to the 14 inch (small) image. The best location for the small image is at 100 cm viewing distance, whereas; for the large image ranged from 60 cm to 100 cm viewing distance.

2.2 Effect of vertical gaze on surgeon's physical workload, mental workload and task performance

2.2.1 Aim

The aim of the study was to test the hypothesis that placing image display at the operating field decreases surgeon's mental and physical workload and hence improve his/her task performance.

2.2.2 Materials and methods

Materials and methods of the study were the same as in the previous study except the monitor location (section 2.1.2). The same subjects were enrolled and each subject completed the study in one session.

2.2.2.1 Monitor positions

The monitor was placed in front of the surgeon at two viewing levels relative to the surgeon's eye: at the surgeon's eye level and at the level of the surgeon's hands. The monitor was tilted to face the surgeon so that the visual axis was perpendicular to the monitor plane and to the line joining the surgeon's eyes. A special monitor stand was used to adjust monitor location. In the two levels, the distance between the centre of the monitor and the surgeon's eyes was kept constant at 1 metre.

2.2.2.2 Statistical analysis

Because the data were not normally distributed, nonparametric tests were used (Friedman's Analysis of Variance test and Wilcoxon Matched Pairs Signed Ranks test). The significance level was set at <0.05. Descriptive data are presented in median and interquartile range.

2.2.3 Results

2.2.3.1 Posture

2.2.3.1.1 Effect of gaze down set up on surgeon's posture

Table 23 presents the median and interquartile range (IQR) of postural angles for gaze down and eye level monitor positions. There was a significant differences in head and neck posture between the two set up ($p<0.05$). There was no significant difference in thoracic bending ($p>0.05$).

Table 23: The median (IQR) of postural angles (degrees) for gaze down and eye level image location

		Gaze down		Eye level		
Angle	**Subjects**	**Median**	**IQR**	**Median**	**IQR**	**p**
Gaze angle	10	7.01	21.8	31	21.16	0.005
Head angle	10	138.83	7.37	149.32	23.04	0.047
NA-b	10	123.89	17.12	133.47	8.28	0.012
NA-v	10	48.71	17.98	41.96	9.98	0.008
T-b Angle	10	135.85	8.08	137.68	7.67	0.17

P values, according to Wilcoxon Signed Rank test

2.2.3.1.2 Effect of time-on-task on posture

In addition to the effect of monitor height on neck angle relative to the vertical, time had also a significant influence. Figure 22 shows the median (IQR) NA-v at the beginning, middle and end of the test session for gaze down and eye level monitor positions. During the test period the NA-v increased significantly ($p< 0.05$) for eye level position but not for gaze down condition. All other angles did not change significantly with time for the two conditions.

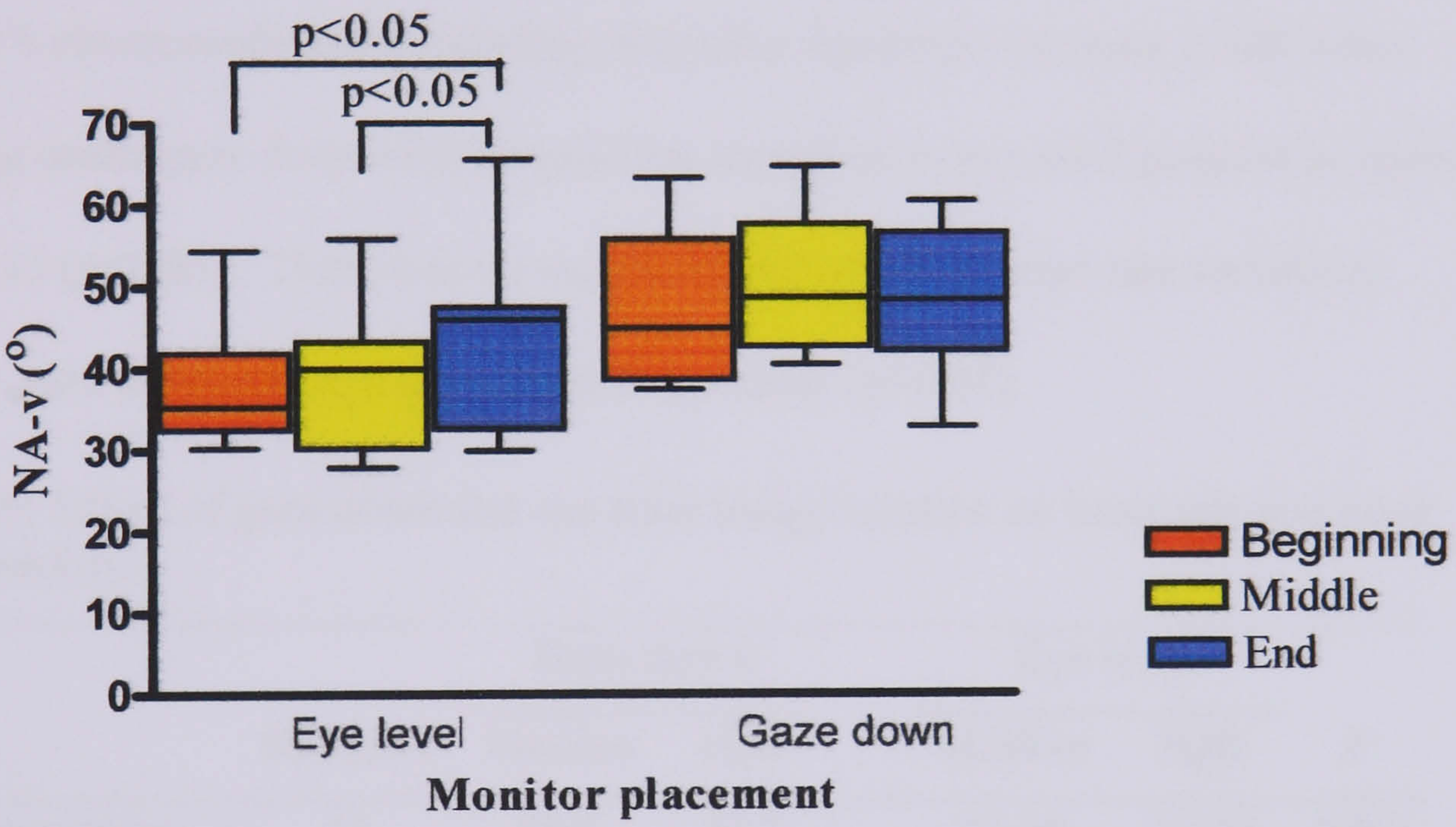

Figure 22: Effect of time-on-task on neck angle relative to the vertical

2.2.3.2 Muscle workload

Table 24 presents the median (IQR) of integrated EMG as an index of muscle activity. Integrated EMG was not standardised as there was little muscle work during rest (Backs et al., 1994). Muscle activity changed significantly in the trapezius muscle ($p< 0.05$). The activities of other registered muscles were not affected by the monitor height.

Table 24: Median (IQR) of muscles integrated EMG (mVs) in gaze down and eye level image location

		Gaze down		Eye level		
Muscle	**Subjects**	**Median**	**IQR**	**Median**	**IQR**	**p**
Sternocleidomastoid	10	7.35	7.46	7.22	6.64	0.07
Trapezius	10	5.96	5.62	6.77	1.51	0.04
Deltoid	10	0.97	0.59	0.75	0.52	0.09
Erector spinae	10	2.66	2.86	2.66	2.87	0.50

P values according to Wilcoxon Signed Rank test

2.2.3.3 Mental workload

Surgeon's electrocardiogram recording showed a significant increase in HR when operating under gaze down monitor position compared to eye level position as shown in table 25 ($p<0.05$). There was no significant difference in heart rate variability between gaze down and eye level monitor positions ($p>0.05$).

Table 25: Effect of gaze down and eye level image location on heart rate and heart rate variability

		Gaze down		Eye level		
	Subjects	**Median**	**IQR**	**Median**	**IQR**	***P***
HR (Beats/min)	10	88.8	37.2	83.60	22.00	0.02
LFn (Arbitrary units)	10	79.10	24.58	75.35	17.98	0.88
HFn (Arbitrary units)	10	18.20	12.53	16.60	16.10	0.76
LF/HF	10	4.20	5.75	5.35	8.38	0.76

P values, according to Wilcoxon Signed Rank test

2.2.3.4 Performance

Table 26 shows the median and interquartile range of suture execution time, suture placement error score, knot execution time and knot quality score with the gaze down and eye level positions. There was a significant difference in knot execution time ($p<0.05$) and suture placement error score ($p<0.05$). Surgeons performed interrupted suturing more quickly and precisely with gaze down position. There was no significant difference in knot quality score between gaze down and eye level positions ($p>0.05$).

Table 26: Effect of gaze down and eye level on task quality and efficiency

		Gaze down		**Eye level**		
Performance	**Subjects**	**Median**	**IQR**	**Median**	**IQR**	p
Suture execution time (Sec)	10	91.22	24.33	140.00	78.38	0.04
Error placement score (mm)	10	16	11.25	19.5	18.38	0.03
Knot execution time (Sec)	10	55.98	12.72	63.65	22.13	0.04
Knot quality score (%)	10	21.32	12.12	21.03	21.95	0.8

P values, according to Wilcoxon Signed Rank test

2.2.4 Discussion

Subjects assumed a more flexed spine position for the gaze down position than the eye level position. This change in posture was expected since the height and the angle of monitor were altered resulting in a change in visual target location. Subjects may potentially respond to a lower monitor location in three ways (Burgess-Limerick et al., 1998): (1) posture may remain constant while gaze angle relative to the head lowers; (2) the gaze angle relative to the head may be maintained by rotating the head anteriorly through some combination of trunk, cervical, or atlanto-occipital flexion; or (3) both head orientation and gaze angle relative to the head may alter.

Ergonomics research has consistently supported the third alternative (Villanueva et al., 1996). The viewing angle in our study changed from about 0° to the horizontal to about 30° below. However, the average changes in head (10°), neck relative to the body (10°) and neck relative to the vertical (7°) posture only accounted for 26°, suggesting a change of around 4° in eye position between the two conditions. This suggests that in "gaze down" position, surgeons did not rotate head anteriorly by the same angular extent as the change in gaze angle relative to the horizontal. Straker and Mekhora found a similar pattern using low and high visual display unit (VDU) monitor placement, with head (5°), neck (6°) and trunk (3°) changes accounting for 13° of the 20° change in viewing angle, leaving 7 for change in eye position (Straker & Mekhora 2000). This indicates that changes in monitor height are accompanied by changes in both head inclination and eye position relative to the head. Therefore gaze angle and neck posture are interrelated and they should not be viewed as independent aspects of the monitor location. Lower monitor placement allows for a wider variety of comfortable neck postures while allowing visual comfort (Ankrum & Nemeth 1995). Burgess-Limerick and Ankrum reported in their series that subjects preferred monitor heights lower than eye-level recommendations (Burgess-Limerick et al., 1998). They concluded that lower monitor heights are likely to reduce both visual and musculoskeletal discomfort.

There was no greater inter-subject variation in both gaze down and eye level positions. The absence of inter-individual variation suggests that there could be an ideal posture generalisable to all laparoscopic surgeons.

Time affected neck posture relative to the vertical in the eye level position but not in the gaze down position. This change in neck posture with time is attributed to a change in head tilt at the cervical joints without alteration at the atlanto-occipital joint. This indicates that surgeons became tired toward the end of the eye level position sessions with some loss of concentration. To compensate for that they decrease the viewing distance by moving the head forward closer to the monitor. The decreased EMG activity in trapezius when working with the gaze down position is in consistent with the study by Kumar and Scaife (Kumar & Scaife 1979). Kumar and Scaife found that electromyographical amplitude of the trapezius and subjective ratings of discomfort were both decreased with lower monitor placement. Straker and Mekhora reported that trapezius activity was not significantly different when working in high and low monitor positions (Straker & Mekhora 2000). Sternocleidomastoid, deltoid, and erector spinae muscles EMG activity was not significantly different when working in the two monitor positions.

The increase in heart rate with gaze down position in the second experiment could be attributed to the effect of neck flexion on autonomic modulation of the heart. Head down Neck flexion results in a parasympathetic withdrawal from the heart in addition to sympathetic activation which suggest an influence of the otolith organs on autonomic modulation of the heart (Lee et al., 2001; Normand et al., 1997; Ray & Hume 1998). However; head down neck flexion has no effect on skin sympathetic outflow (Ray et al., 1997).

Task performance was better when the monitor was positioned at ports level compared to eye level. Placing the endoscopic image in the same field as the surgeon's hands decreases operating time for laparoscopic appendisectomy by 10%, compared to placing the monitor at eye level (Erfanian et al., 2003). Hanna et. al., reported that task quality improves when the image display is placed in front of the operator, at the level below the head and close to the hands (Hanna et al., 1998c).

There was no significant difference in the objective quality of knots because subjects reached the plateau of their proficiency gain curve as they performed a lot of knots during their training in the endoscopic surgical courses before participating in the study. This also explains why there was no significant difference between subjects.

2.2.5 Limitations

Methodological limitations associated with this study include:

- The probability of picking up electrical signals from the adjacent muscle groups (cross talk);
- The use of rest integrated electromyogram data as a reference point;
- Similar to the body of related research, this study was limited by the a small number of participants (surgeons) (Berguer et al., 1998; Berguer et al., 2001a; Emam et al., 2001; Uhrich et al., 2002);
- The study was conducted in a controlled environment. In reality, interpretation of surgical images and performance of operations take place in a wide variety of environments, with differing levels of noise, light, and equipment quality. The decision to perform the study in a controlled environment was made in an effort to ensure that differences in results could be attributed to experimental factors.

2.2.6 Conclusion

Placing the image display system at the operating field decreased the shifting in surgeon's body posture, decreased the tapezius muscle recruitment, and improved the surgeon's performance.

2.3 Effect of gaze down image location on surgeon's mental workload and task performance

2.3.1 Aim

Due to the effect of head position on Heart Rate and Heart Rate Variability (HRV) measures we could not conclude the effect of vertical gaze on mental workload during laparoscopic task performance using HRV in the previous study. Therefore the aim of this study was to investigate the influence of gaze down position on surgeons' mental workload using other mental workload measuring methods.

2.3.2 Material and methods

The endoscopic task consisted of performing Dundee Endoscopic Psychomotor Tester (DEPT) under standardised endoscopic conditions. The vertical level of the monitor relative to the surgeon's manipulation workspace (hands) was investigated.

2.3.2.1 Subjects

Ten surgeons aged 34-38 years (mean = 35 years) participated in the study. All participants were right-handed with normal or corrected-to-normal vision. Each subject completed two runs of DEPT under each image display position in one session. Each session consisted of two experimental conditions. The order of the image display position during each session was in a random sequence for each surgeon.

The experimental session for each subject was divided into 5 periods. These include: (a) time for attaching electrodes to the subjects; (b) baseline recording period; (c) familiarisation period to familiarise subjects with experimental set up and DEPT task; (d) test period; (e) 15 minutes break between each of the two conditions. Skin conductance and blinking rate were recorded continuously during the test period. Skin conductance was also recorded during the baseline period and the rest period.

2.3.2.2 Monitor positions

The monitor was placed in front of the surgeon at two viewing levels relative to the surgeon's eye: at the surgeon's eye level (eye level placement) and at the level of the surgeon's hands (gaze down placement). The monitor was tilted to face the surgeon so that the visual axis was perpendicular to the monitor plane and to the line joining the surgeon's eyes. A special monitor stand was used to adjust monitor location. In the two levels, the distance between the centre of the monitor and the surgeon's eyes was kept constant at one metre.

2.3.2.3 Task

The Dundee Endoscopic Psychomotor Tester (DEPT):

The DEPT consists of a stainless steel probe mounted in a gimbal mechanism; the probe is designed to be inserted by the operator through a series of circular holes on a target plate (Hanna et al., 1996). The target object consists of a black front disk with a number of holes that overlay a white back plate. An endoscope is connected to a display system to provide the visual interface between the operator and the probe–target field.

Each run consists of 37 target holes. The holes are addressed in a random sequence, which is generated by the system software. As blinking rate is affected by the change in gaze, the order of the holes was given verbally by the examiner order to control the change in gaze direction between the endoscopic display monitor and the DEPT computer monitor. Starting from the backstop position, the operator aims the probe through the centre of the hole until it touches the back plate within the allocated time for each task, which was 10 sec. DEPT is controlled by a microprocessor (with dedicated software) that also records data on performance in real time. An error is registered by the system when contact of the probe is made with the rim of the hole or when the subject exceeds the time allowed to complete one target hole. The system also records the force exerted by the probe on the back plate and the spatial orientation (x, y, and z coordinates) of the tip of the probe in relation to the centre of each hole.

2.3.2.4 Videoendoscopic equipment

The endoscopic setup consisted of a Sony monitor (Sony, Tokyo, Japan), a forward-viewing Hopkins II telescope (Karl Storz, Tubingen, Germany), and a light source and a light cable (Karl Storz). The telescope was introduced into the DEPT facing the target plate at a distance of 22 cm from its centre. The camera was adjusted and white balanced before each run.

2.3.2.5 Skin conductance activity recording apparatus

Skin conductance level was recorded using 2701-SC Simple Scope SCL/SCR Data Collection System (UFI, California, USA). The system was adjusted to get a sample rate of 10Hz. Skin conductance level was measured by applying a small alternating current (AC) signal through two electrodes, placed on the palmer surface of middle phalanx of the index and middle fingers of the subject's non dominant hand. The response is seen as a change in conductance (decrease in resistance) of the skin with time. Skin conductance level data were analysed as difference scores from the average over the baseline and rest periods to minimise inter-individual variability (Backs et al., 1994).

2.3.2.6 Blinking rate recoding apparatus

Blinking rate was recorded using MT8 radiotelemetry system (MIE Medical Research Ltd, Leeds, UK). The MT8 radiotelemetry system is a wireless precalibrated EMG system. The data are analyzed by the software to provide enveloped EMG. Enveloped EMG is a signal processing technique which is used to gain an 'average trend of EMG activity. It is used because the RAW EMG signal is relatively useless because it fluctuates in amplitude too quickly and too often. Endogenous blinking rate was measured by using two reusable 4-mm Ag/AgCL Electromyographic (EMG) electrodes filled with gel as a conductive electrolyte. One electrode was placed 10 mm under the pupil of the left eye and the second was positioned just above the eyebrows of the same eye. The subject was grounded through an 8 mm electrode positioned lateral to the left eye. The electrodes sites were cleaned carefully with alcohol pad before electrode application with eyes closed to keep out the alcohol fumes. The sites were then allowed to dry before attaching the electrodes. The electrodes were attached using specific adhesive collars. A miniature preamplifier with gain setting of x8600 was used to reduce interference and artefact to a minimum, resulting in a high signal to noise ratio and stable baseline. Endogenous blinking rate was calculated manually from the enveloped EMG signal. The number of eye blinks was calculated for the same period of time for each condition.

2.3.2.7 Control measures

Room illumination, temperature and humidity were controlled through all the study. Subjects performed the study first thing in the morning in one session. Each subject should have slept minimum 6 hours the night before the day of study in order to perform the experiment.

The experimental setup of this study was standardized by placing the DEPT on a table of adjustable height so that when the surgeon held the probe and pointed to centre of the plate with the shoulder adducted, the elbow formed a right angle.

2.3.2.8 Outcome measures

2.3.2.8.1 Mental workload measures:

- Blinking rate:

The blinking rate is defined as the rate of endogenous blinking per minute.

- Skin conductance level:

The measure of skin conductivity between two electrodes placed on the palmer surface of middle phalanx of the index and middle fingers of the subject's non dominant hand.

2.3.2.8.2 Task quality measures

- *Execution time of the task*:

Time for each targeted hole was clocked by DEPT from when the probe reaches the centre of the hole at the target plate until it makes contact with the back plate.

- *The applied force*:

The force exerted by the probe upon the target object is recorded when contact has been made with the back plate.

- *The flight trajectory*:

The angular deviation of the tip of the probe in the x and y coordinates.

- *The success score*:

Success is defined as the successful completion of the task by the operator within the allocated time and tolerance limit of the system.

2.3.2.9 Statistical analysis

The data of DEPT, blinking rate, and skin conductance activity were not normally distributed. Nonparametric tests were used (Friedman's Analysis of Variance test and Wilcoxon Matched Pairs Signed Ranks test). Significance was set at the 5% level.

2.3.3 Results

2.3.3.1 Mental workload

Table 27 shows that gaze down monitor placement set up resulted in low SCL compared to the eye level monitor placement set up ($p<0.05$). This indicates that subjects performed the task with lower mental workload under gaze down set up. However; there was no significant difference in blinking rate ($p>0.05$).

Table 27: Effect of gaze down and eye level image location on skin conductance and blinking rate

		Gaze down		Eye level		
Mental workload	**Subjects**	**Median**	**IQR**	**Median**	**IQR**	**p**
Blink/minute	10	23	4.5	20.5	5.75	0.67
Skin conductance level (μmho)	10	3.33	1.33	3.62	1.42	0.022

P values, according to Wilcoxon Signed Rank test

2.3.3.2 Task quality

Wilcoxon Matched Pairs Signed Ranks test was used to determine the effect of gaze down and eye level monitor placement task performance (Table 28). There was a significant differences in vertical deviation, total deviation and execution time ($p<0.05$) between the low monitor placement and high monitor placement. Subjects performed the task in a shorter execution time and in more precise manner under "gaze down" condition. No significant differences was found in the horizontal deviation, force applied on the target or success score ($p>0.05$).

Table 28: Effect of gaze down and eye level image location on DEPT parameters

		Gaze down		Eye level		
Task quality	**Subjects**	**Median**	**IQR**	**Median**	**IQR**	**p**
Y-deviation (U)	10	130.85	67.1	118.6	87.93	<0.001
X-deviation (U)	10	84.35	63.08	89.65	48.85	0.85
Total deviation (U)	10	200.7	106.75	194.5	89.4	0.005
Force applied (g)	10	186.1	164.23	287.1	225.18	0.24
Execution time (sec)	10	2.65	0.8	3.15	0.6	0.02
Success score	10	10.5	15.75	15	19	1

P value, According to Wilcoxon Matched Pairs Signed Ranks test

2.3.4 Discussion

Research in the field of human-computer interaction has shown that both performance and kinematic characteristics are influenced by the degree to which work space and display space are spatially aligned (Lyons et al., 1999). Baker et. al., investigated whether gaze direction modified the pattern of finger movement activation in human cerebral cortex using functional magnetic resonance imaging (Baker et al., 1999). They suggested that skeletomotor processing in the cerebral cortex is consistently modified by gaze direction signals.

The operating room set up using standard laparoscopic image display divides the surgeon's gaze between the monitor and the operative field. This results in disturbed hand eye coordination, thereby interrupting the pattern flow of the surgical task and effects task efficiency (Erfanian et al., 2003; Hanna et al., 1998c; Ibbotson et al., 1999). To counter the feeling of misorientation, surgeons usually glance at the orientation of the instrument shaft outside the patient's body. This quick look helps them to mentally restore the kinematic relation between the instrument handle and the tip on the monitor.

Gaze down set-up during laparoscopic surgery allows the alignment of the operator's head stance with the monitor and manipulation workspace. Thus the kinematic relation between the instrument handle and the tip can be mentally reconstructed more easily. This appears to improve cerebral processing of the image displayed on the monitor and decrease surgeons' mental workload as indicated by the low skin conductance level in this study.

2.3.5 Limitations

- Similar to the body of related research, this study was limited by the a small number of participants (surgeons) (Berguer et al., 1998; Berguer et al., 2001a; Emam et al., 2001; Uhrich et al., 2002);
- The used task (DEPT) is a uni-manual task where as real laparoscopic tasks are bimanual task and
- The study was conducted in a controlled environment.

2.3.6 Conclusions

Gaze down set-up decreased mental workload and improved performance compared to the eye level set-up during simulated uni-manual laparoscopic task performance.

CHAPTER THREE

INFLUENCE OF IMAGING MODALITIES ON MENTAL WORKLOAD DURING LAPAROSCOPIC TASK PERFORMANCE

3. INFLUENCE OF IMAGING MODALITIES ON MENTAL WORKLOAD DURING LAPAROSCOPIC TASK PERFORMANCE

3.1 Aim

Based on section (1.2.1.2.3.1.3) we hypothesised that the currently available pseudo three dimensional laparoscopic imaging systems increases surgeon's mental workload although they might improve task performance. The aim of this comparative study was to test this hypothesis.

3.2 Materials and methods

3.2.1 Task

The test rig consists of a metal plate 10 x 11.5 x 0.5 cm mounted on a wooden board in a trainer box. The plate contains 15 small holes arranged in three rows, each row contain 5 holes. The holes were closed posteriorly by the wooden board in order to keep the pins in place. A plastic cap containing pins and collars was fixed close to the metal plate. The task was pick-and-place task. Each subject was instructed to pick up one of the pins from the plastic cap using two laparoscopic graspers and put it in a hole in the metal plate starting from the left side of the first row. Each pin must be followed by a collar; insertion of several pins and then the placement of collars were not permitted. The first row was used for practice for each imaging modality.

3.2.2 Video-endoscopic systems

The laparoscopic imaging system was Zeiss Medilive 3-D-video system (Carl Zeiss, Oberkochen, Gerymany) (Figure 23), with a Grunding monitor (Model M70-791 IDTV, Gerymany), Zeiss 3D camera (model 313520-9100), xenon light source (model 301), and 30° Zeiss endoscope (model 31350-9040) with fiberoptic light cable of 48 mm diameter. Surgeon had to wear shutter glasses (Figure 24) in order to obtain the three dimensional image. Zeiss laparoscopic imaging system was used for both 2-D and 3-D because it has the facility to be set up as a 2-D or 3-D using a switch button on the back of the monitor.

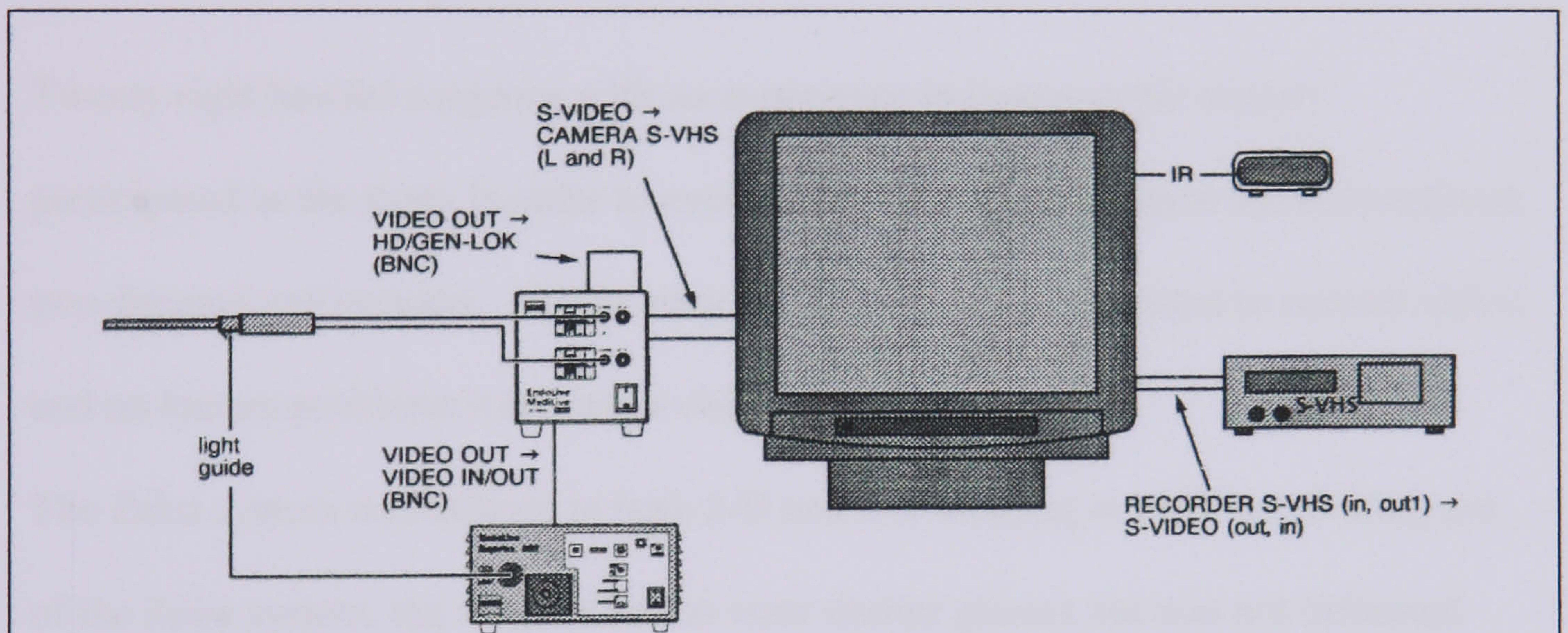

Figure 23: Zeiss Medilive 3-D video system

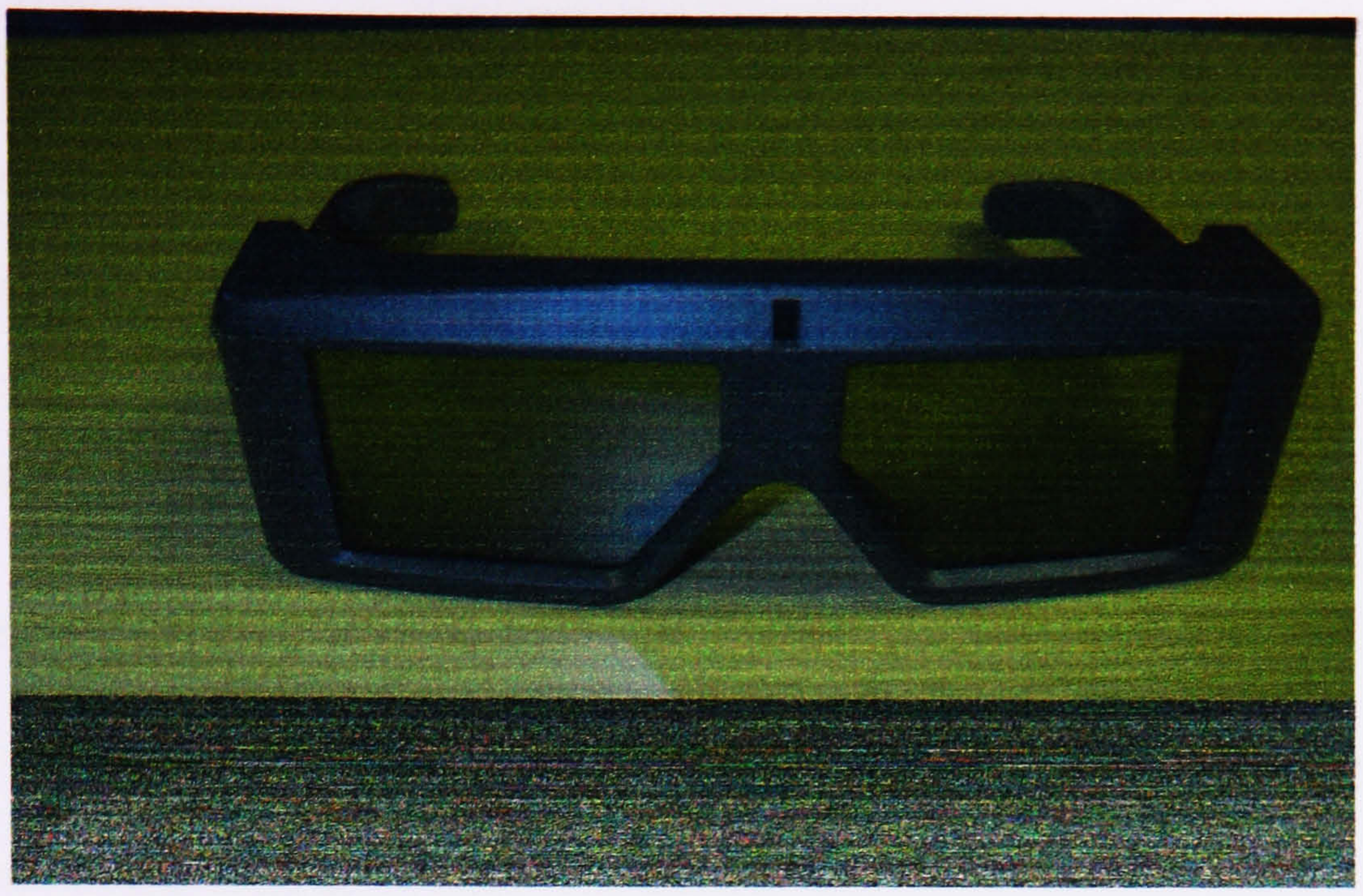

Figure 24: Shutter glasses for the 3-D system

3.2.3 Surgeons and practice

Twenty right handed surgeons with no experience in laparoscopic surgery participated in the study in order to avoid the effect of adaptation to the conventional two dimensional systems. All the surgeons had normal or corrected to normal vision and no known problems with stereo vision.

The Zeiss system was utilised in both 2-D and 3-D imaging modalities. During use of the Zeiss system, the surgeon had to wear shutter glasses but was not informed whether the 2-D or 3-D mode was being used. However, surgeons were asked about the imaging modality used at the beginning of the 2D and 3D runs in order to ensure each subject perceived the three dimensional image with the 3D system. Direct view was used as a control condition. The top of the experimental box was replaced by a strip of wood 5 cm in width, so that subjects can watch directly as they perform the task using laparoscopic instruments.

Each surgeon performed the task twice with each modality during two consecutive practice runs. Each run consisted of performing the task once with each modality allocated by random sequence. In all, 120 procedures were performed. Subjects' skin conductance level and blinking rate were continuously recorded during the baseline period, each run, and rest periods between the runs.

3.2.4 Control measures

The monitor was placed in front of the surgeon at eye level and at a distance of one metre. The optical axis-to-target view angle was 90 degrees, with the endoscope-to-target distance being fixed at 70 mm. The camera was white balanced before each run. The endoscopic trainer was placed on a table of adjustable height so each surgeon held the grasper with the shoulder adducted the elbow at right angle, and the forearm in the horizontal plane. The experiment was conducted at 9.00 o'clock in the morning before starting any of the working duties; in the same environment; illumination and under controlled room temperature (using air conditioner with temperature and humidity control and display facility). Surgeon had to have at least 6 hours sleep and not included in any duty the night before the day of the study.

3.2.5 Outcome measures

3.2.5.1 Mental workload measures:

- Skin conductance level

Skin conductance level was recorded using 2701-SC Simple Scope SCL/SCR Data Collection System (UFI, California, USA) (See section 2.2.2.3).

- Endogenous blinking rate:

Blinking rate was defined as number of blinks per minute. Blinking rate was recorded using MT8 radiotelemetry system (MIE Medical Research Ltd, Leeds, UK) (See section 2.2.2.4).

3.2.5.2 Performance measures:

- Execution time:

Defined as the time taken to place the rods and collars in all the holes starting from when the subject grasps the graspers. The execution time was recorded using a stop watch.

3.2.6 Statistical analysis

As the data were not normally distributed, nonparametric tests, including the Friedman's analysis of variance (ANOVA), and Wilcoxon matched-pairs signed-rank test, were used. Significant was set at the 5% level. Skin conductance level data were analysed as difference scores from the average of the baseline and rest periods in order to minimise the interindividual variability (Backs et al., 1994).

3.3 Results

3.3.1 Mental workload

Skin conductance level, blinking rate, and task execution time for each imaging modality are presented in table 29. The lowest mental workload was encountered with normal vision compared to 2D and 3D for blinking rate and skin conductance (Figures 25 and 26). Also surgeons have significantly lower blinking rate ($p<0.05$) and skin conductance ($p<0.05$) using 2D compared to 3D modality.

Table 29: Median and interquartile range (IQR) of execution time, blinking rate, and skin conductance level for the three viewing conditions

Parameter	Subjects	Direct	2D	3D	*P**
Execution time (sec)	10	300 (90)	585 (385)	540 (285)	< 0.01
Blinking rate/min	10	2.40 (3.45)	3.30 (5.33)	3.90 (6.00)	< 0.01
Skin conductance level (μMho)	10	5.01 (5.04)	5.57 (6.57)	6.16 (6.47)	< 0.01

*Friedman analysis of variance.

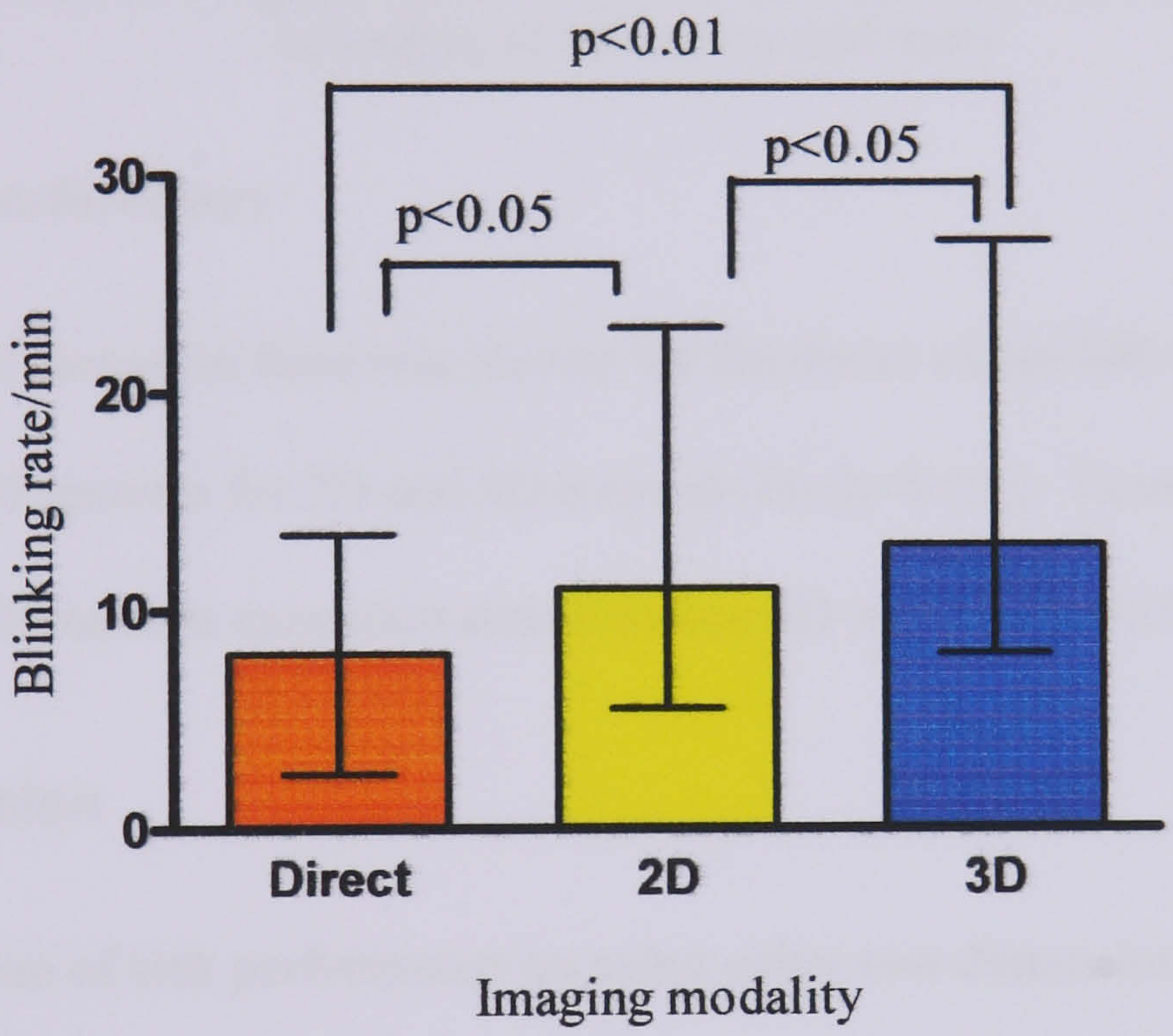

Figure 25: Effect of imaging modality on median (IQR) blinking rate (*P*, according to Wilcoxon rank test)

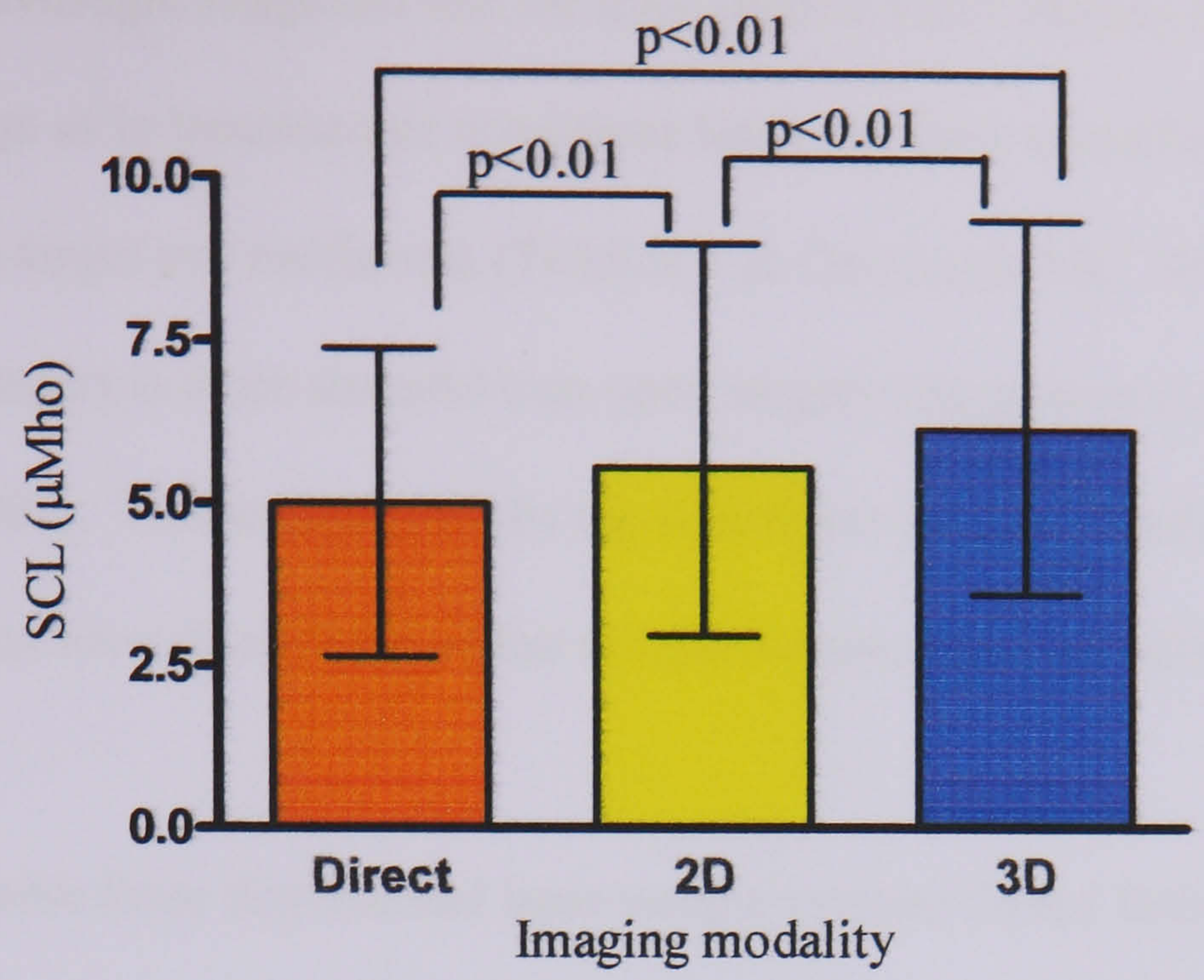

Figure 26: Effect of imaging modality on median (IQR) skin conductance level (*P*, according to Wilcoxon rank test)

3.3.2 Task performance

The median of execution time was shorter for the direct vision 300 seconds compared to 585 and 540 seconds for 2D and 3D respectively ($p<0.01$). There was no significant difference in execution time between 2D and 3D ($p>0.05$).

3.4 Discussion

The degradation of task performance on using either two dimensional or three dimensional laparoscopic systems compared to normal vision is consistent with the previously reported data (Crosthwaite et al., 1995a).

Binocular vision is crucial for the accurate planning and control of reaching and grasping movements (Glennerster et al., 1998; Mon-Williams & Dijkerman 1999; Servos et al., 1992). Under direct vision subjects have good depth cues and view of the taget geometry allowing an accurate estimate and reaching of the target position. Standard image displays used in laparoscopic surgery lead to degradation of both monocular and binocular depth cues because of anti-cues imposed by the monitor.

Tendick and Cavusoglu suggested that the poor geometry and distortions of the workplace image as in laparoscopic conditions leads to a poor mental model of the locations of the target and instrument (Tendick F & Cavusoglu MC 1997). Therefore laparoscopic surgery is more stressful than open surgery (Berguer et al., 2001b; Bohm et al., 2001). This is confirmed by the significant increase in blinking rate and skin conductance level from direct vision to laparoscopic vision conditions during our study.

Currently available three dimensional laparoscopic systems do not follow the basic rules of binocular vision afforded by the human eyes. They lack vertical binocular disparity and convergence, have fixed horizontal disparity and ignore binocular overlap (Cuschieri A 1995). As a result they provide a pseudo three dimensional image that could not decrease task execution time compared to conventional two dimensional systems in our study and in other reported studies (Hanna et al., 1998b; Hanna & Cuschieri 2000).

By efficiently integrating information from all simultaneously available depth cues, the brain can derive more accurate and robust estimates of the three dimensional geometry (positions, orientations, and shapes in three dimensional space) (Jacobs 1999; Johnston et al., 1993). Cue integration is important for depth perception. With stereoscopic systems there is conflict between different depth cues. When using stereoscopic systems, the eyes must accommodate to the distance of the TV display while the convergence angle of the eyes is determined by the stereoscopic disparities. Thus, a conflict between accommodation and convergence, which are closely coupled in normal vision, is likely to arise (Hofmeister J et al., 2001). In stereoscopic systems, if the scaling of monocular cues and stereoscopic cues are not matched, the addition of stereoscopic viewing is likely to be detrimental to visual scaling and hence to motor control. Furthermore, matching a stereoscopic view with a monocular reference (like instrument) is nontrivial when the camera, the instruments, and the surgeon can move (Hofmeister J et al., 2001). The increase in blinking rate and skin conductance level when using the three dimensional compared to the two dimensional system suggests that the remapping process is easer while working under 2D compared to stereoscopic system. Therefore, task performance using current three dimensional imaging systems was associated with more mental workload compared to standard two dimensional systems. This can explain the problems with the available stereoscopic systems which include visual discomfort, fatigue, and headaches. Mueller et al., reported in their study that both the inexperienced and experienced candidates became tired earlier and had more headaches with the stereoscopic system (Mueller et al., 1999).

3.5 Limitations

- The study was conducted in a controlled environment;
- Only one imaging system model was used therefore the results might reflects the effectiveness of this system and not the other 3 dimensional systems.
- Only surgeons with no experience in laparoscopic surgery were enrolled in the study. Therefore, the results of the study might not be applicable to the laparoscopic surgeons.

3.6 Conclusions

1. Task efficiency for surgeons with no experience in laparoscopic surgery is degraded with the use of video laparoscopic imaging systems compared to normal vision.

2. There was no improvement in laparoscopic task performance on using Zeiss Medilive 3-D video system as three dimensional video laparoscopic imaging compared to using it as two dimensional system.

3. The non laparoscopic surgeons experienced more mental workload on using either two dimensional or three dimensional laparoscopic imaging systems compared to normal vision.

4. The two dimensional display for Zeiss Medilive 3-D video system caused less mental workload compared to three dimensional display of the same system.

CHAPTER FOUR

INFLUENCE OF INNATE ABILITY AND TRAINING ON MENTAL WORKLOAD, PHYSICAL WORKLOAD AND ACQUISITION OF LAPAROSCOPIC SKILLS

4. INFLUENCE OF INNATE ABILITY AND TRAINING ON MENTAL WORKLOAD, PHYSICAL WORKLOAD AND ACQUISITION OF LAPAROSCOPIC SKILLS

4.1 Effect of innate ability and task repetition on mental workload and skill acquisition

4.1.1 Objective

The aim of the study is to test the hypothesis that subjects with high level of visual spatial ability and manual dexterity perform laparoscopic tasks with low mental workload and greater learning ability than those with low visual spatial ability.

4.1.2 Materials and methods

4.1.2.1 Psychological aptitude tests

4.1.2.1.1 Determination of visual-spatial ability

Visual-spatial ability refers to the visual processing of spatial relations of image properties. Anastakis et al., and Wanzel et al., classified visual-spatial ability into five major categories (Anastakis et al., 2000; Wanzel et al., 2003): (1) Edge and surface extraction (low level visual-spatial ability); (2) Edge orientation encoding; (3) Whole object recognition (intermediate level visual spatial ability); (4) Imagery involving the spatial relations of object parts in two dimensional; (5) Imagery involving two dimensional (2D) and three dimensional (3D) whole object rotation and translations (high level visual-spatial ability). Since laparoscopic task performance requires the translation of the displayed 2D image to 3D image in the brain the high level visual-spatial ability was assessed using Space Relations Test. The Space Relations Test is a subtest of the Technical Abilities Battery of the Differential Aptitude Tests (Psychological Corporation Ltd, London, UK). It measures the ability to reconstruct a three-dimensional object from a two-dimensional pattern and to conceptualize the object when rotated in space. The test consists of 50 tasks. For each task, there is one unfolded test diagram and four optional folded patterns, one of which results in the correct folded diagram (Figure 27). The subject has to identify the correct option and to complete the 50 tasks in 25 minutes. The norm for this test is based on an analysis of 226 students (age range 16-29, mean age 17 years) engaged in a variety of Advanced GNVQ courses in UK, some within schools and some within colleges of further education (DAT for selection technical abilities battery manual 1996).

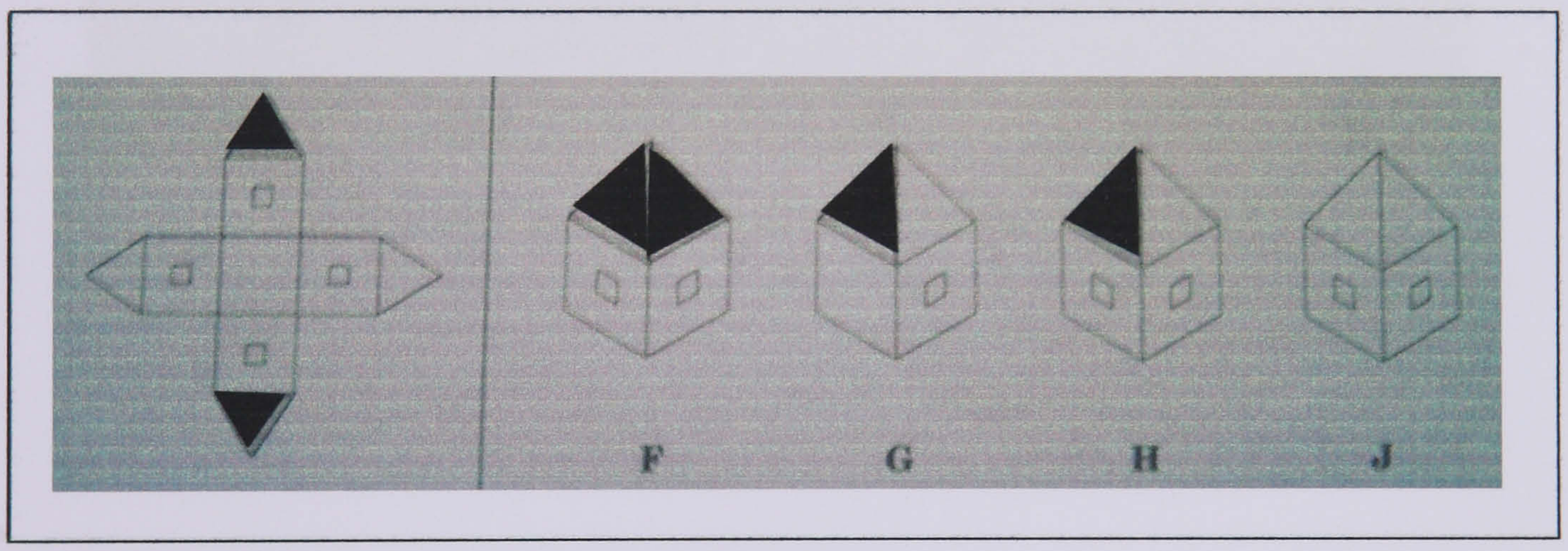

Figure 27: Space relation test

4.1.2.1.2 Determination of manual dexterity

The Crawford Small Parts Dexterity Test Parts I and II (Psychological Corporation Ltd, London, UK) is a performance test designed to measure eye-hand coordination and manual dexterity (Figures 28, 29). Part I entails using tweezers to insert small pins in close-fitting holes and to place small collars over the protruding pins. Part II requiring the insertion of screws in close-fitting threaded holes using screwdriver. The measured end-point is duration, the lower the execution time the better the performance.

Figure 28: Crawford Small Parts Dexterity Test part I

Figure 29: Crawford Small Parts Dexterity Test part II

4.1.2.2 Laparoscopic task

Using 5.0-mm laparoscopic grasper and scissors, the subjects had to cut between two black rectangles drawn 4mm mm apart on the upper layer of a double layer of latex loosely stretched over a cup with a diameter of 68 mm (Figure 30). The task assembly was mounted with Velcro inside a trainer box. Only the upper layer was to be cut. The measured endpoints were the execution time and error rate.

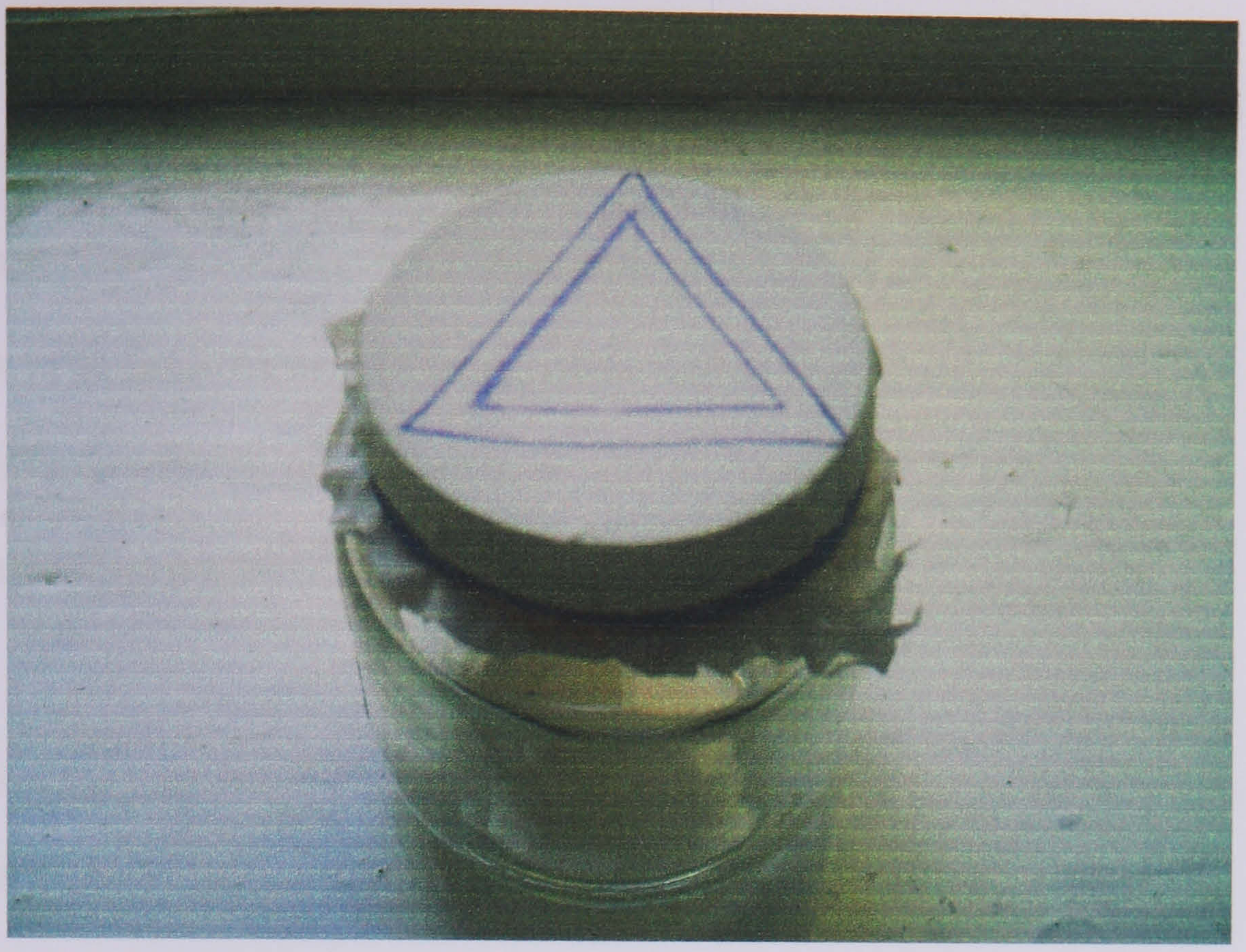

Figure 30: Simulated laparoscopic dissection task

4.1.2.3 Subjects and practice

Twenty female students from the higher institute of nursing (The higher institute of nursing, Houn, Libya) with no experience in endoscopic surgery participated in the study. The study was explained in detail to the institute dean and subjects by a research fellow. Permission was taken from the institute's dean and consent was obtained from each subject before starting the study. The study was divided into 3 sessions: (1) aptitude testing session; (2) training session; and (3) experimental session.

During the aptitude session the subjects were tested on two aptitude tests: the Crawford Small Parts Dexterity Test (execution time indicates manual dexterity) and the Space Relations Test (correct scores reflects visio-spatial ability).

In the training session the subjects received information on: (1) the displaying of the three-dimensional operating field in a two-dimensional image during laparoscopic surgery, (2) the fulcrum effect of ports in laparoscopic surgery. Crothers et al., demonstrated that when the fulcrum effect is artificially eliminated, by inverting the monitor image around the y-axis, the performance of the novices improves significantly (Crothers et al., 1999). Therefore; each subject performed a pick and place task to be familiarised with laparoscopic task performance and to minimise the fulcrum effect. Subjects were asked to transfer 5 metallic collars one by one, between two lines drown on the bottom of the training box, using laparoscopic grasper.

The experimental session for each subject was divided into: (a) time for attaching electrodes to the subjects; (b) 5 minutes baseline recording period; (c) test period during which each subject performed four trials of simulated laparoscopic dissection task (d) 5 minutes break between each of the four trials. Skin conductance, heart rate and heart rate variability were recorded continuously during each task and break period.

4.1.2.4 Control measures

Entry sites for the instruments provided manipulation and elevation angles of 60° with equal azimuth angles (Hanna et al., 1997c). The monitor was placed in front of the subject at ports level and at a distance of 1 metre. The camera was white balanced before each run. The endoscopic trainer was placed on a table of adjustable height so each subject held the grasper and scissors with the shoulder adducted the elbow at right angle, and the forearm in the horizontal plane. The experiment was conducted in the morning before starting any of the working duties in the same environment, illumination and under controlled room temperature. Subject should have slept at least 6 hours the night before the day of the study.

4.1.2.5 Outcome measures

4.1.2.5.1 Mental workload measures:

- Skin conductance level (SCL) (see section 2.2.2.3);
- Heart rate (HR) and
- Heart rate variability (HRV) (see section 2.1.2.5).

4.1.2.5.2 Laparoscopic task performance measures:

- Execution time:

The execution time was measured from the moment the candidate grasped the handles of the scissors and grasper to the time when the instruments were released on completion of the task.

- Error rate

Errors were awarded as follows: one point for each cut across a black line, and one point for each perforation of the lower latex layer.

4.1.2.6 Statistical analysis

Heart rate, heart rate variability, skin conductance level data were analysed as difference scores from the average over the baseline and rest periods(Backs et al., 1994). As the data were not normally distributed, nonparametric tests, including the Friedman's analysis of variance (ANOVA), Wilcoxon Signed Ranks and Mann-Whitney U tests were used. Significant was set at the 5% level.

4.1.3 Results

4.1.3.1 Mental workload

Table 30: Median (IQR) of workload measures during each trial of the simulated laparoscopic dissection task

Parameter	subjects	Trial 1	Trial 2	Trial 3	Trial 4	p
Heart rate (Beats/min)	10	104.95 (17.51)	108.25 (18.95)	107.11 (20.67)	104.17 (14.59)	0.44
Normalised low frequency (Arbitrary units)	10	73.89 (37.43)	64.09 (33.50)	71.21 (24.71)	64.58 (32.58)	0.28
Normalised low frequency (Arbitrary units)	10	26.11 (37.43)	35.91 (33.50)	28.79 (24.71)	35.42 (32.58)	0.28
Low frequency/High frequency ratio	10	2.58 (2.97)	1.79 (3.19)	2.51 (2.72)	1.89 (3.31)	0.28
Skin conductance level (μMho)	10	15.51 (11.4)	15.80 (7.48)	15.67 (5.86)	16.55 (11.01)	0.90

P according to Friedman one way ANOVA Test

Table 31: Median (IQR) of heart rate and heart rate variability for low and high visio-spatial ability groups

	Heart rate (beats/min)			**Normalised low frequency** (Arbitrary units)		
	Low SRT score group	**High SRT score group**	***P***	**Low SRT score group**	**High SRT score group**	***P***
Subjects	10	10		10	10	
Trial 1	107.06 (40.42)	104.37 (20.15)	0.52	57.43 (46.02)	73.89 (21.54)	0.42
Trial 2	108.26 (38.57)	106.18 (20.55)	0.51	53.07 (40.35)	66.71 (20.32)	0.91
Trial 3	107.07 (37.28)	104.54 (22.06)	0.51	65.27 (46.89)	71.22 (15.33)	0.56
Trial 4	104.17 (21.60)	107.22 (18.19)	0.13	70.71 (55.81)	64.38 (20.90)	0.52

P: Mann-Whitney test

4.1.3.2 Performance

Spearman rank correlation coefficients showed a moderate negative correlation between the visio-spatial ability (space relation test score) and laparoscopic task execution time during each trial and for all trials (Figures 31-35). There was almost no correlation between the visio-spatial ability and the laparoscopic task error rate during each trial or for all trials (Figures 36-40).

There was a weak but not significant positive correlation between the Crawford Small Parts Dexterity Test (CSPDT) execution time and the laparoscopic task execution time and error rate during each trial and for all trials.

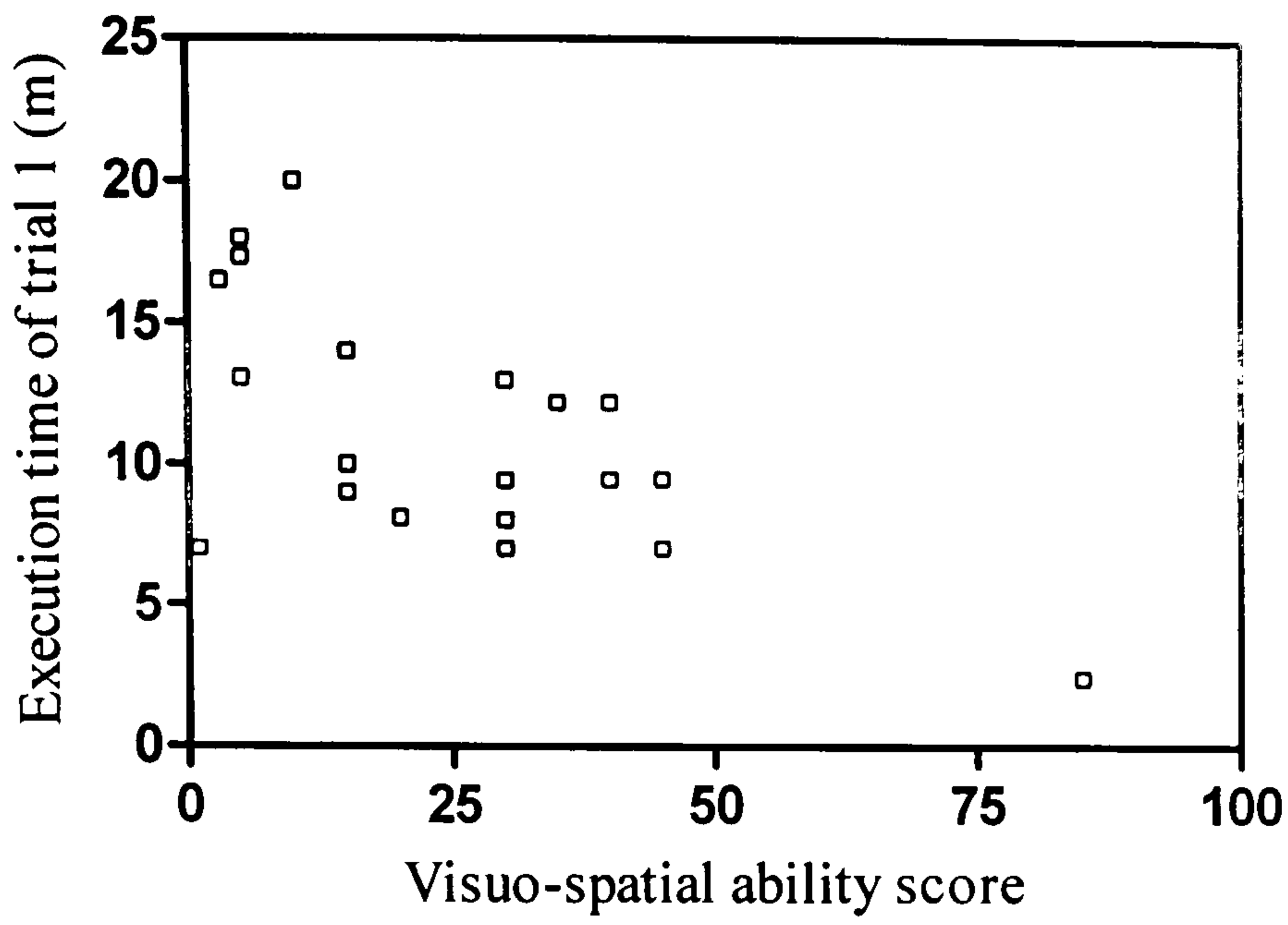

Figure 31: Correlation between visio-spatial ability and first trial execution time (r = -0.50, p = 0.02)

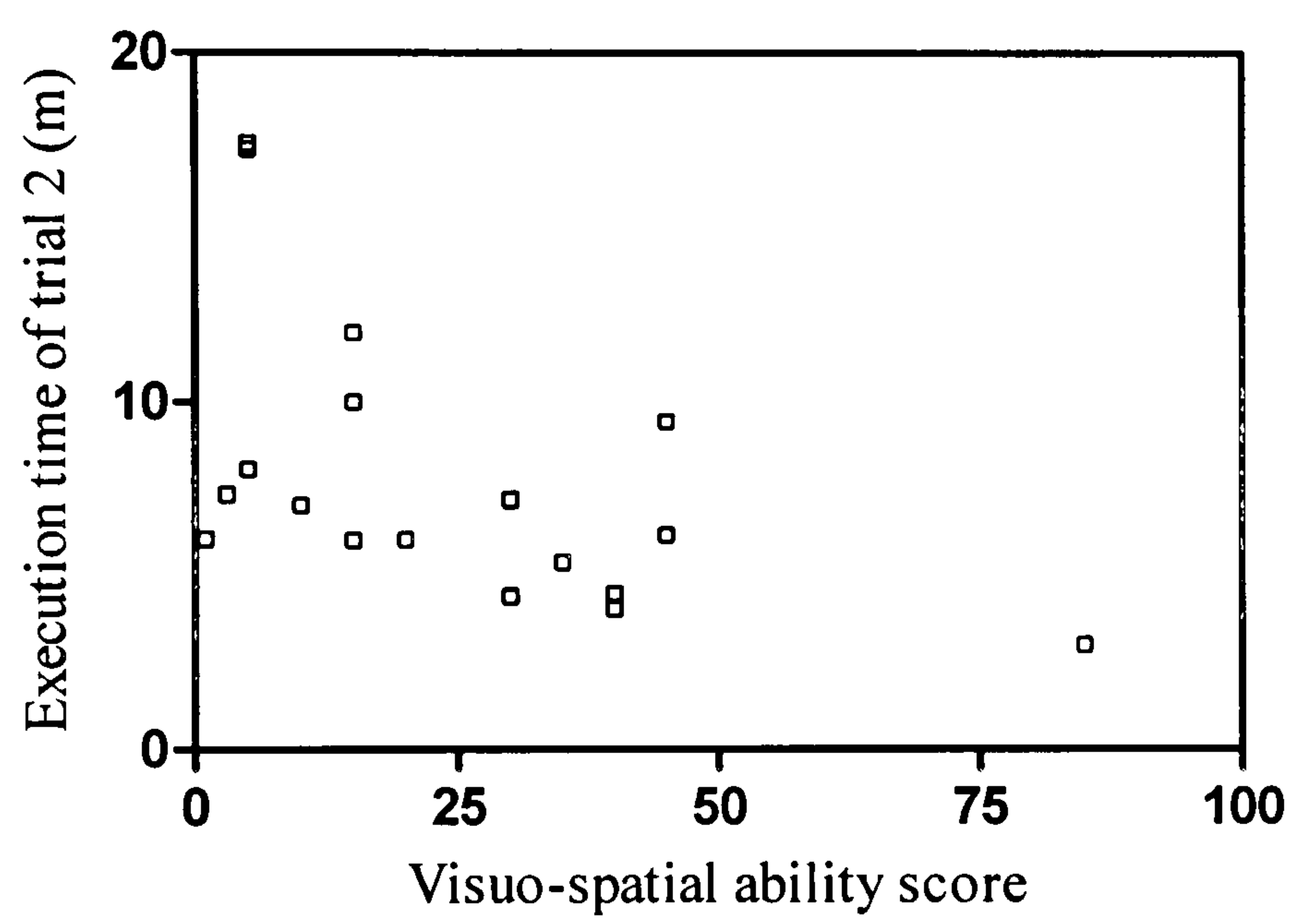

Figure 32: Correlation between visio-spatial ability and second trial execution time (r = -0.53, p = 0.02)

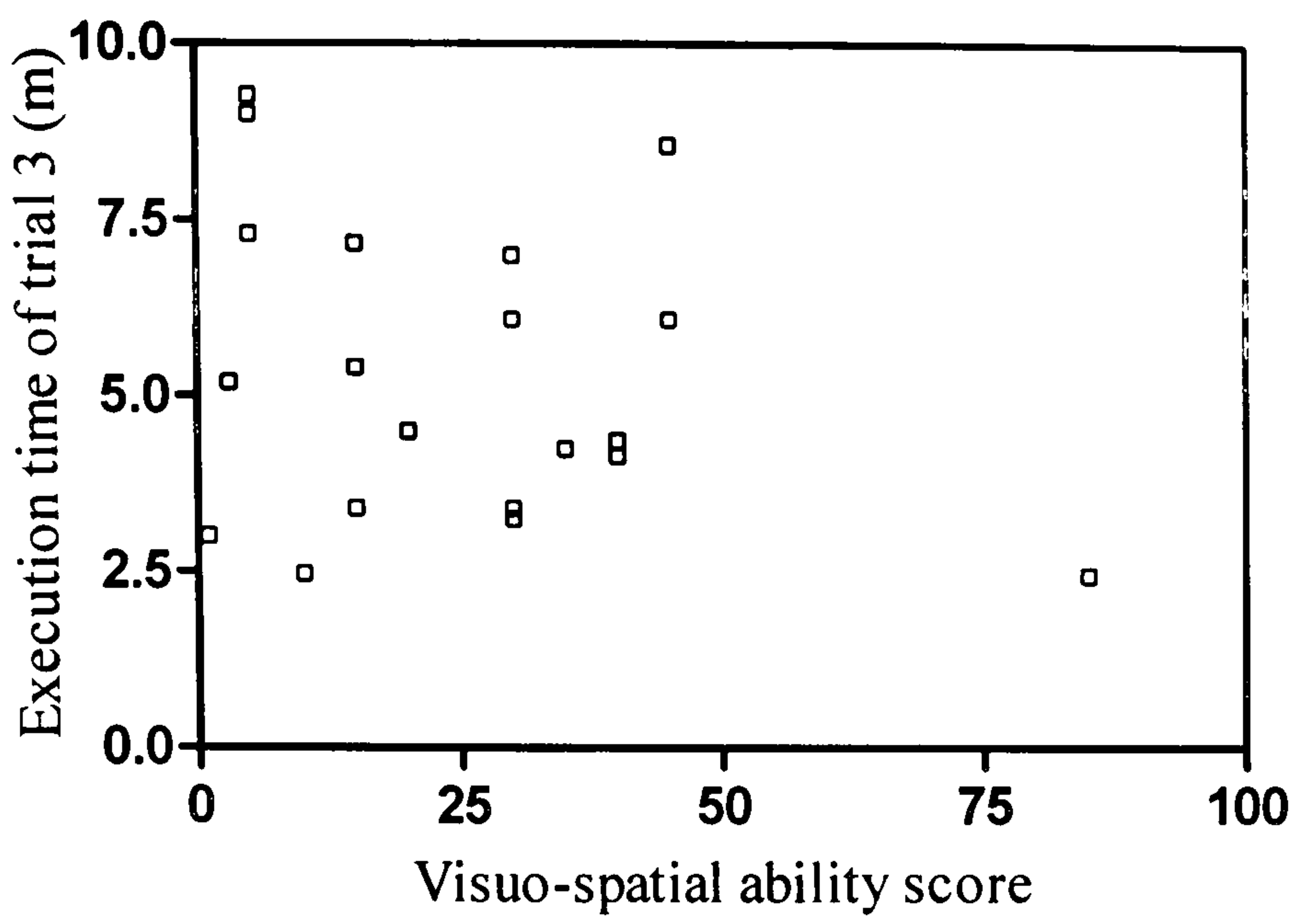

Figure 33: Correlation between visio-spatial ability and third trial execution time (r = -0.17, p = 0.46)

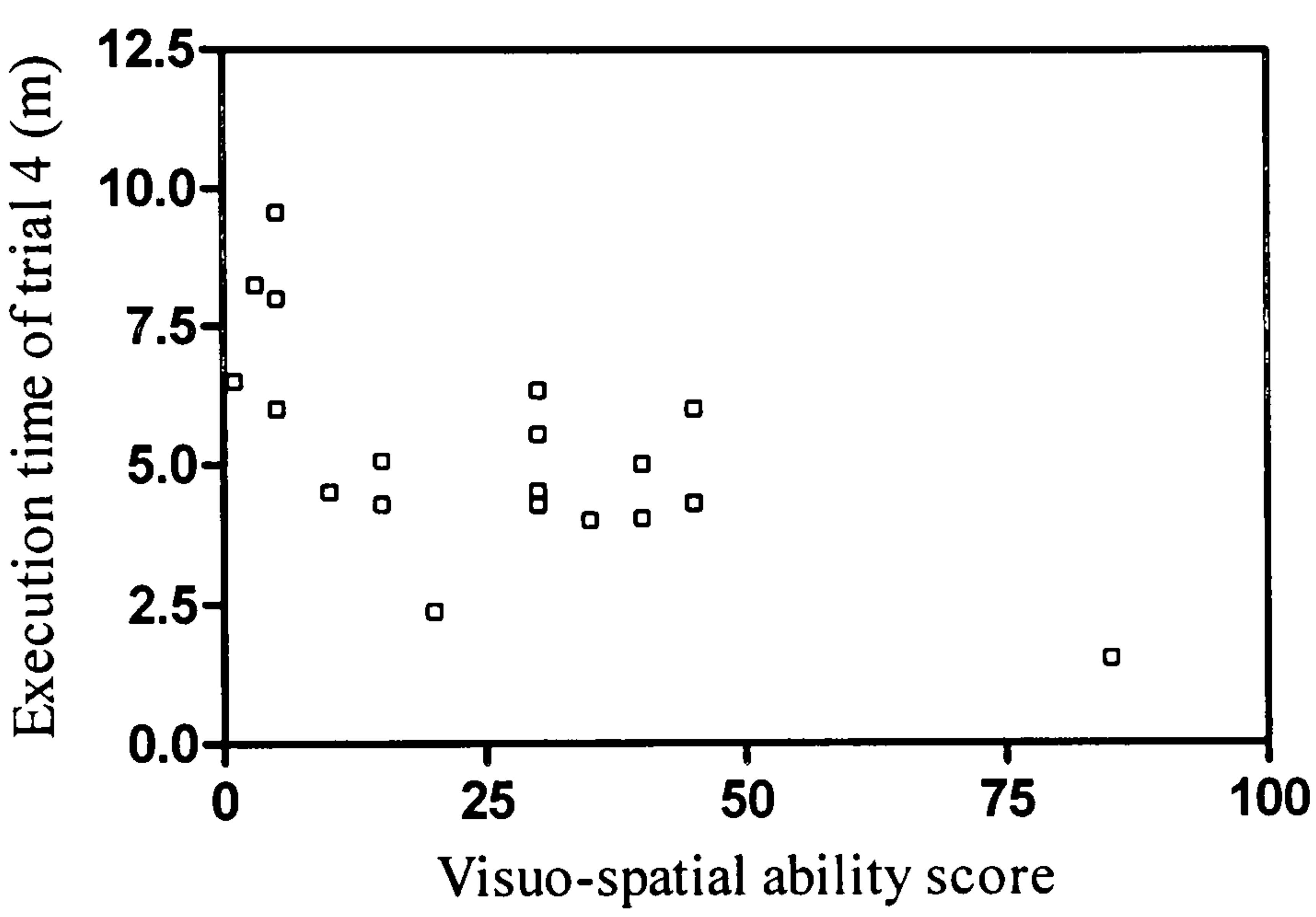

Figure 34: Correlation between visio-spatial ability and fourth trial execution time (r = -0.60, p = 0.01)

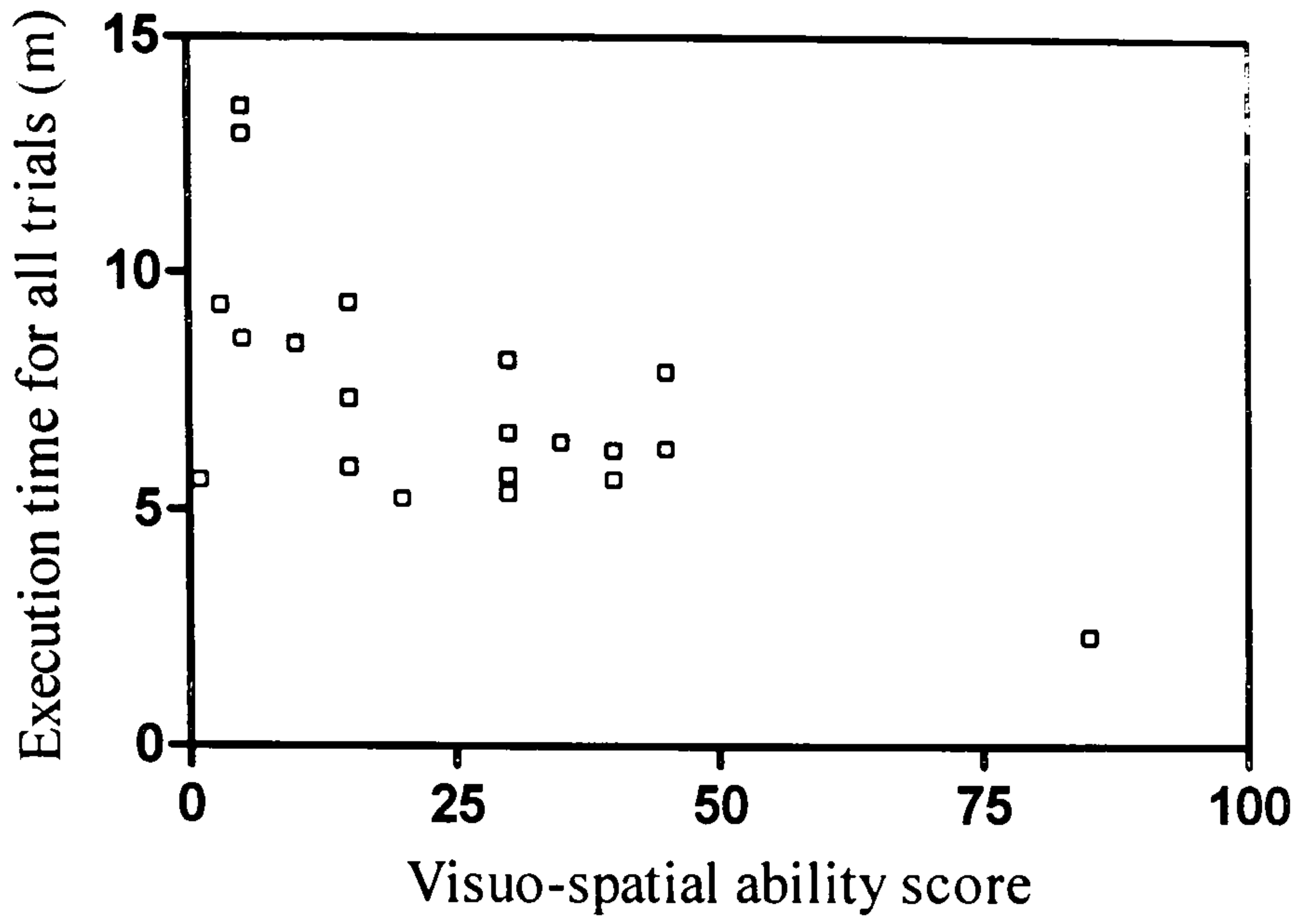

Figure 35: Correlation between visio-spatial ability and all trials execution time (r = -0.50, p = 0.03)

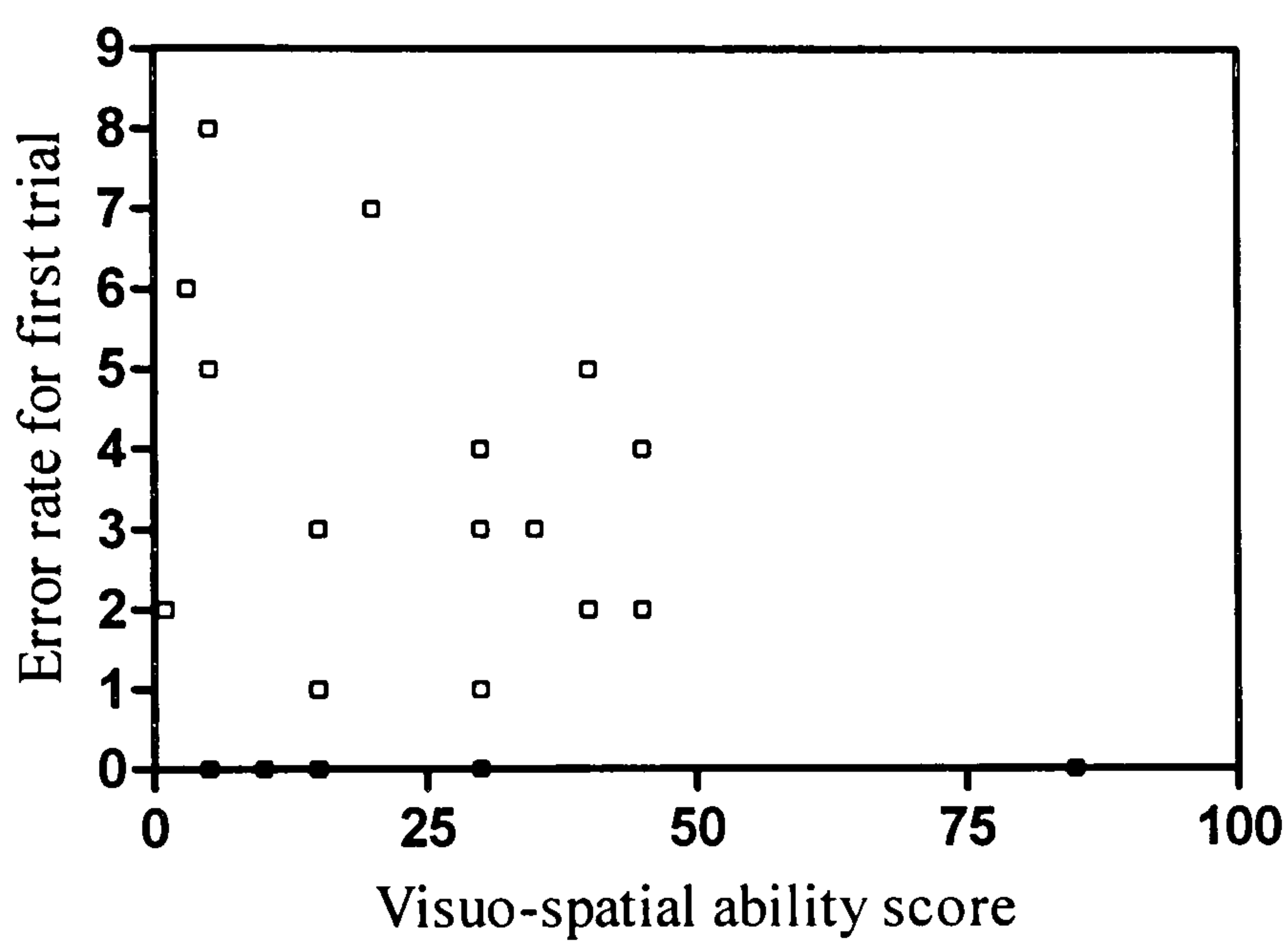

Figure 36: Correlation between visio-spatial ability and first trials error rate (r = -0.12, p = 0.62)

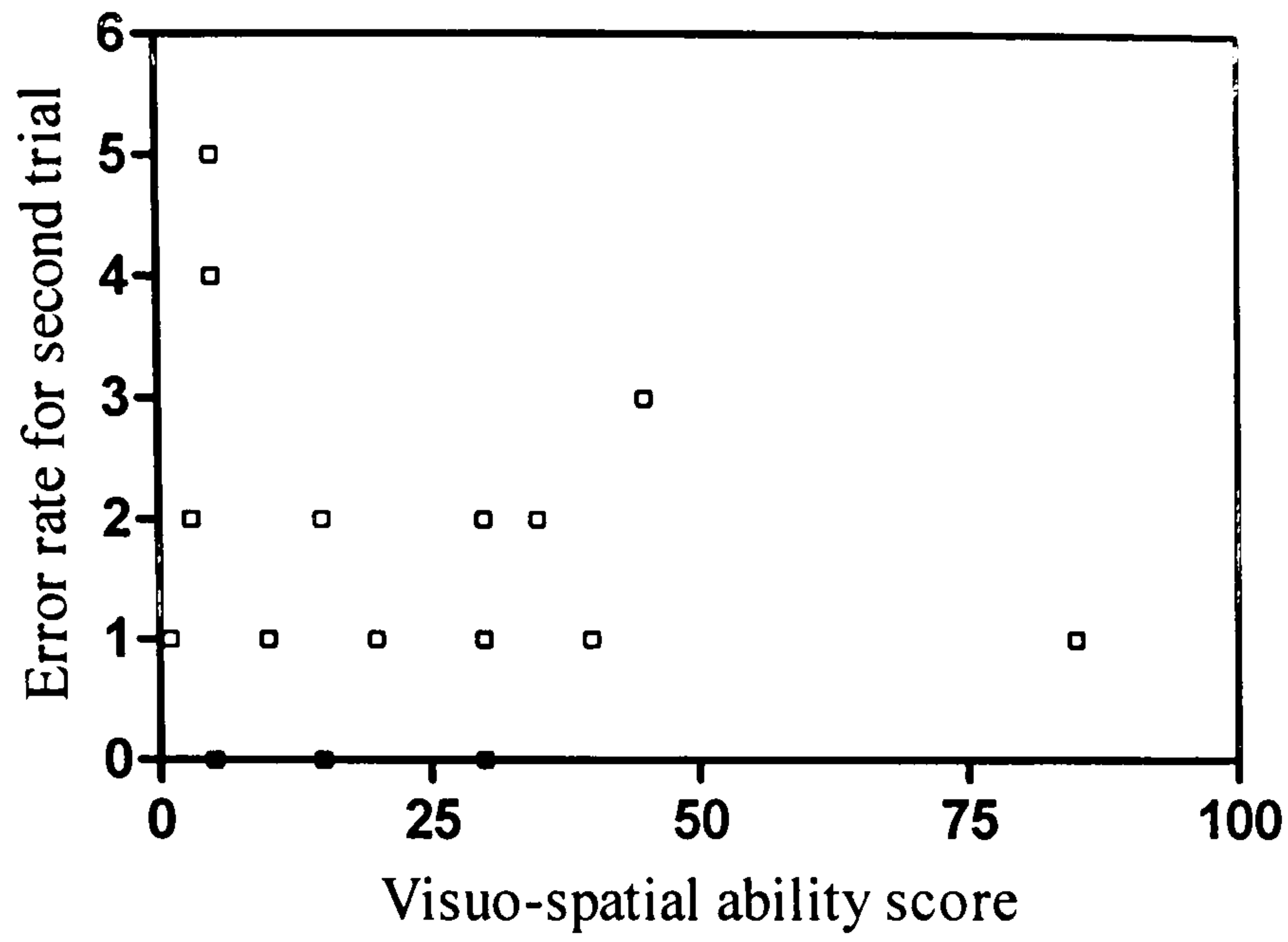

Figure 37: Correlation between visio-spatial time and second trial error rate (r = -0.05, p = 0.84)

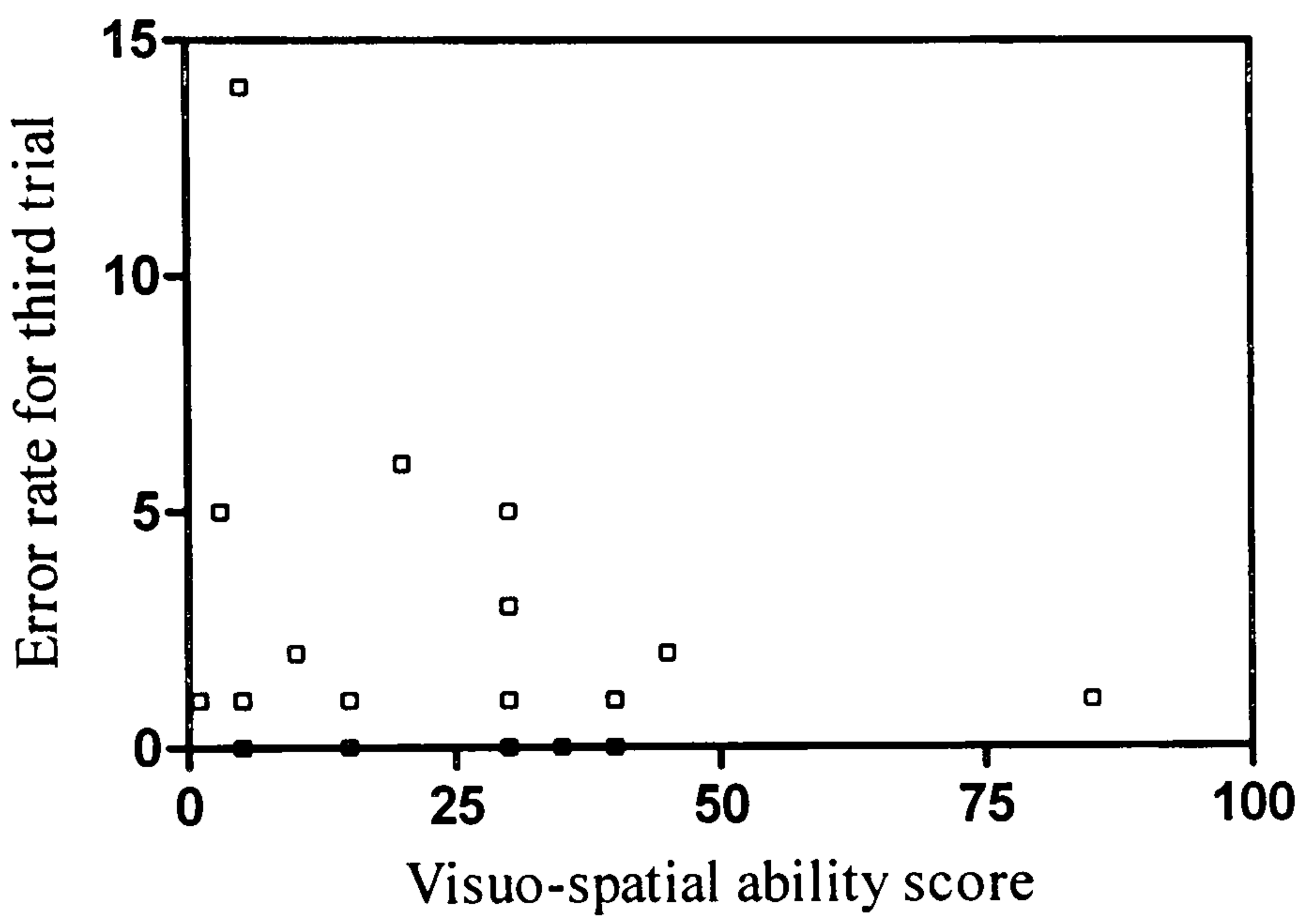

Figure 38: Correlation between visio-spatial ability and third trial error rate (r = -0.13, p = 0.59)

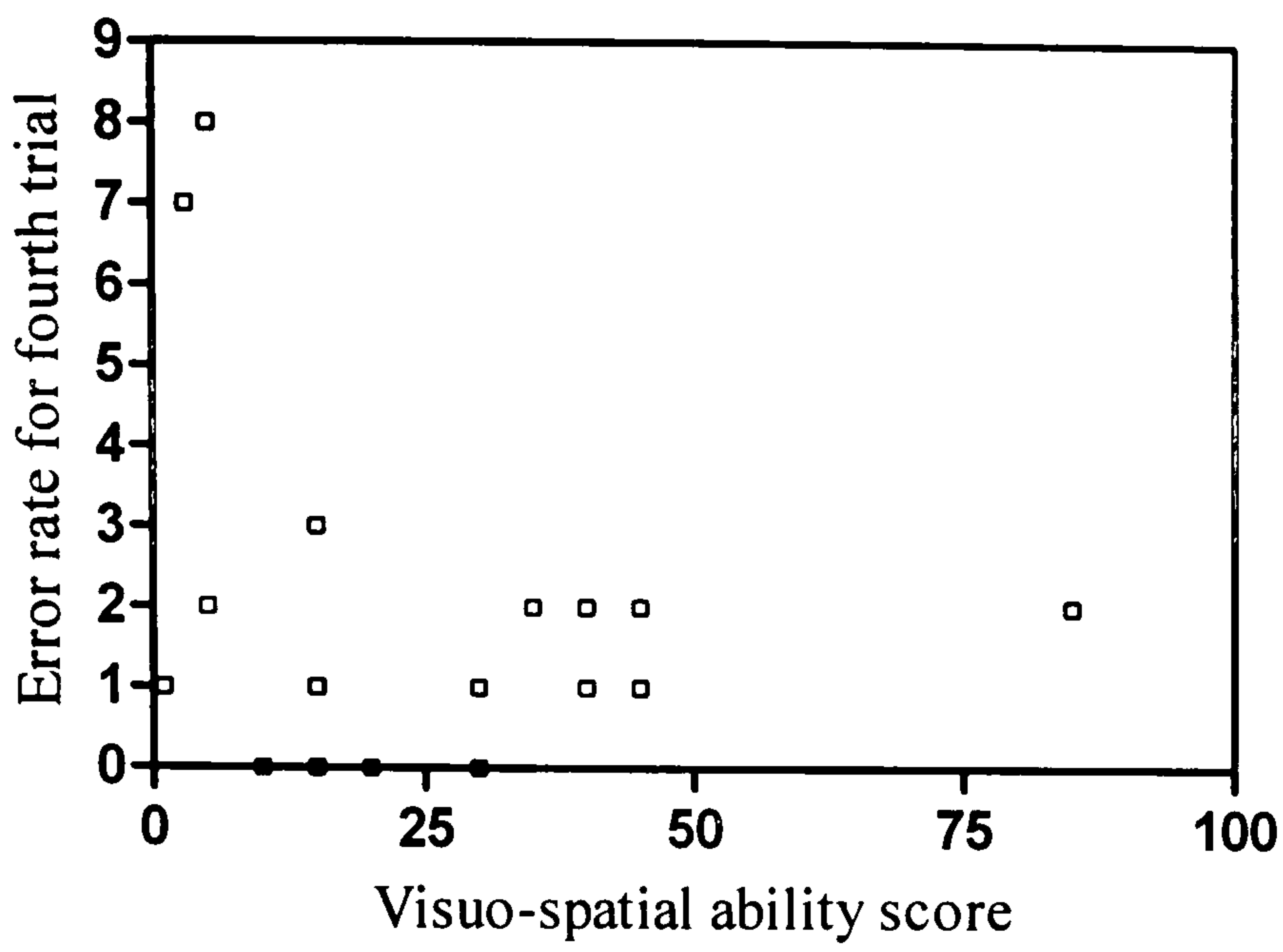

Figure 39: Correlation between visio-spatial ability and fourth trial error rate (r = -0.14, p = 0.56)

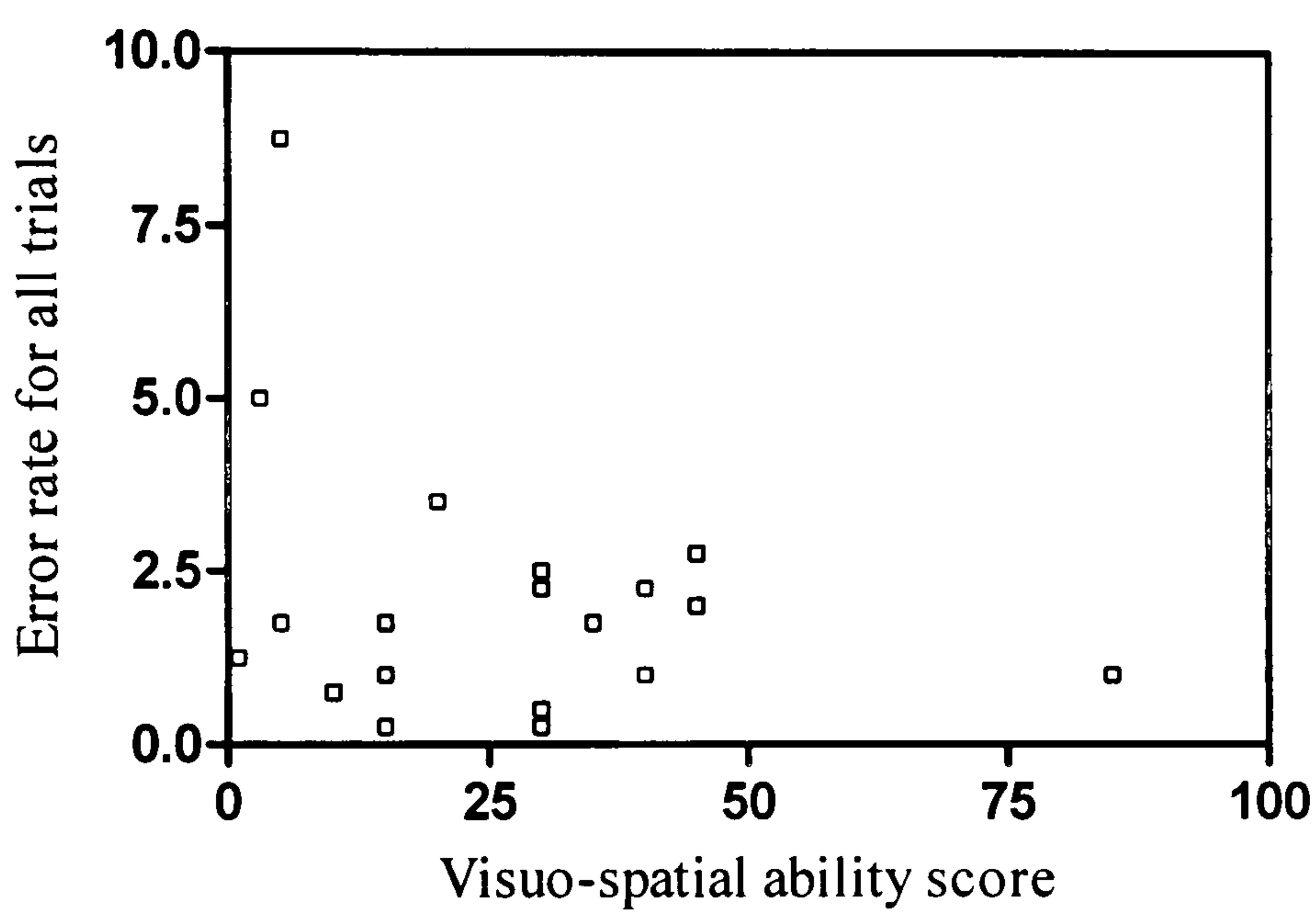

Figure 40: Correlation between visio-spatial ability and all trials error rate (r = -0.06, p = 0.81)

The students were divided according to their space relation test (SRT) score into two groups of 10 subjects: low SRT score group (less than 25% of the norm) and high SRT score group (more than 25% of the norm). The high SRT score group performed the laparoscopic task more efficiently compared to the low SRT score group during the first and second trials ($p<0.05$- Mann-Whitney test) (Figure 39).

This difference in the laparoscopic task execution time between the two groups decreased and became insignificant with task repetition during the third and fourth trials ($p>0.05$). There was a significant difference in laparoscopic task execution time between all the trials ($p<0.05$- Wilcoxon rank test) except between trials 3 and 4 ($p>0.05$) for each group (Figure 41).

There was no significant difference in the error rate between the two groups during any trial ($p>0.05$). However; error rate decreased significantly in trial 4 compared to trial 1 for the high SRT score group ($p<0.05$- Wilcoxon rank test) (Figure 42), whereas; errors enacted during the laparoscopic dissection task did not changed with the four trails of task repetition for the low SRT score group (Wilcoxon rank test, $p>0.05$).

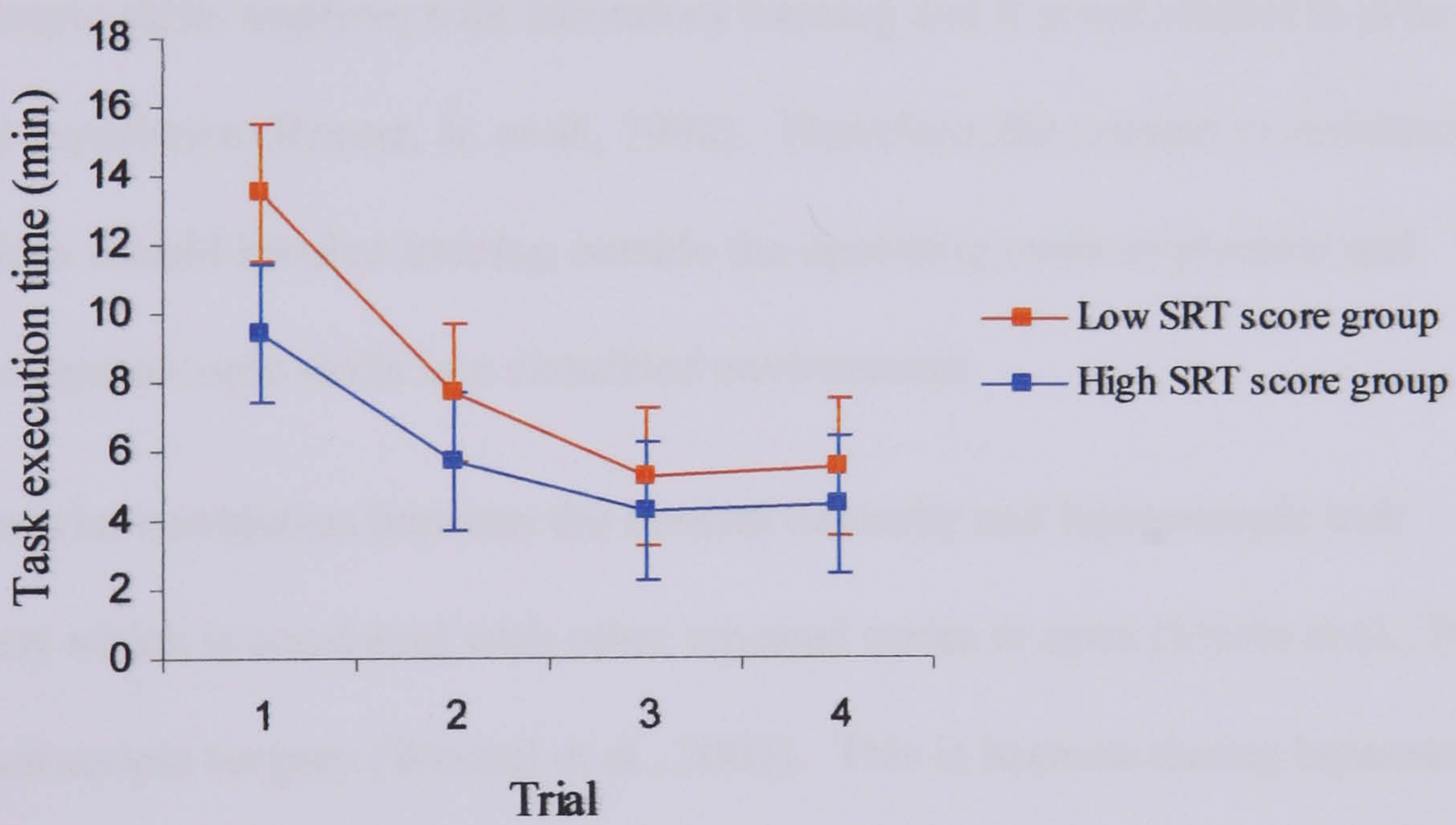

Figure 41: Effect of task repetition on median task execution time

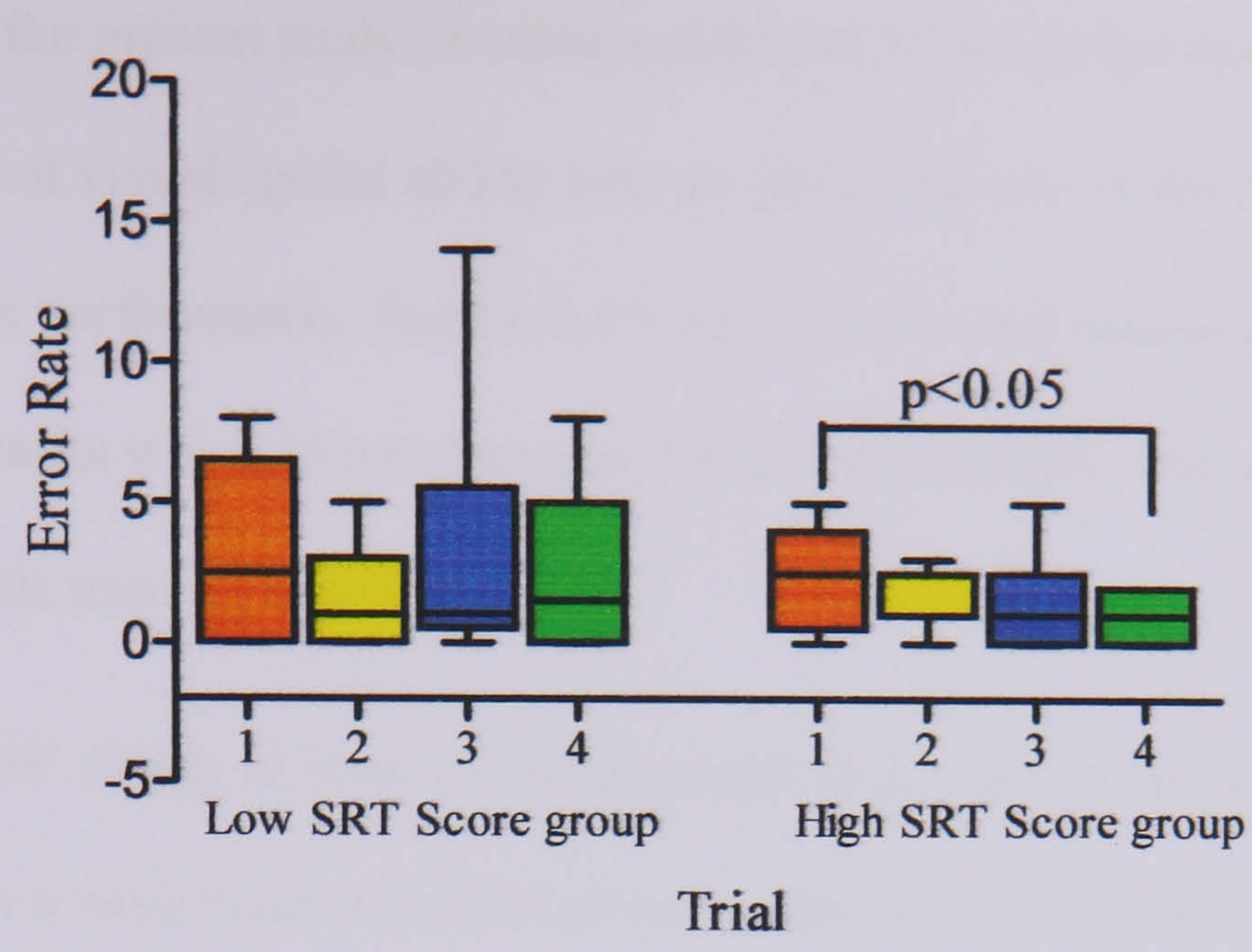

Figure 42: Effect of task repetition on median error rate (*p*, according to Wilcoxon Signed Ranks test)

4.1.4 Discussion

The performance results of the study support the reported series that basic laparoscopic skills improve with laboratory training and it is not related to prior surgical experience (Rosser, Jr. et al., 1998). Therefore; the context of residency curriculum should involve training outside the operating room to practice and enhance laparoscopic skills in a simulated environment.

There was no correlation between the manual dexterity and laparoscopic task efficiency which is consistent with other reported series in open (Steele et al., 1992) and laparoscopic surgery (Wanzel et al., 2003). This is because during laparoscopic task performance hand movement efficiency is determined by spatial perception, processing of virtual information and eye-hand coordination in a magnified virtual field rather than manual dexterity alone (Hanna et al., 1996).

Risucci et al., reported that visual-spatial ability is directly associated with speed in specific laparoscopic dexterity drills (Risucci et al., 2000). This is further enforced by the results of the present study on using a different laparoscopic task. These results suggest that visual-spatial ability play an important role in the proficiency of laparoscopic task performance. Such results improve the understanding of the nature of laparoscopic tasks which in turn helps in the development of well-structured laparoscopic skills training courses.

To assess subjects' ability to learn the laparoscopic task, we compared competency between subjects scored more than 25% of norm and subjects scored less than 25% of norm in the space relation test (SRT). The analysis showed that subjects in the high SRT score group performed the initial two laparoscopic trials more efficiently than subjects in the low SRT score group. However; with task repetition no difference in performance was seen between the two groups in the third and fourth laparoscopic trials. This suggests that visual spatial ability is related mainly to the initial competency in laparoscopic surgery which is consistent with the published surgical (Keehner et al., 2004; Wanzel et al., 2003) and skill acquisition (Ackerman et al., 1988) reports. Ackerman et al. showed that cognitive abilities such as spatial ability are important during the initial phase of learning a new skill, but less important in later phases.

Both high and low space relation test score groups improve their task efficiency with task repetition and reached a plateau will in a short period of training. Only the high score group improved their proficiency by decreasing their error rate with task repetition but not to a level that differed significantly from the low score group. Hence, subjects with low visual-spatial ability might need more supplementary practice and feed back for each new laparoscopic procedure than subjects with high visual-spatial ability. Therefore the acquisition of laparoscopic skills is extremely variable among individuals.

There was no significant decrease in subjects' mental workload with task repetition in the first experiment, i.e. there was dissociation between subject's performance and their mental workload. This is because training period was too short and hence the students' did not reach the automation stage of skill acquisition. As a result students' mental workload did not change with repetition of the laparoscopic task. This underscores the suggestion by Carswell et al., of including mental workload assessment in laparoscopic training programmes (Carswell et al., 2005). In addition, the result highlights the importance of overlearning techniques (repetitions beyond the point of technical competence) in reaching the automation level during the acquisition of basic laparoscopic skills by novice trainees. Automation of a skill can be particularly valuable in retention of that skill during stressful situations which cause decrements in laparoscopic skills (Moorthy et al., 2003a).

4.1.5 Limitations

- Only one visio spatial ability test was used;
- As visio spatial ability decreases with age and as the subjects were students, the application of our results to surgical trainees will be limited.
- The used task was simple, which might not reflect the effect of the visio spatial ability in laparoscopic task performance.

4.1.6 Conclusions

1. Basic laparoscopic skills improve with task repetition in a brief laboratory training course.

2. The context of residency curriculum should take in consideration the effect of innate ability, such as visio-spatial ability, on the acquisition of laparoscopic skills.

4.2 Effect of training on mental workload, physical workload and performance

4.2.1 Objective

The aim of the study was to investigate the hypothesis that training in laparoscopic surgery reduces surgeon's physical and mental workload and improves performance

4.2.2 Materials and methods

4.2.2.1 Task

The task was to perform laparoscopic cholecystectomy on a gallbladder model. The model was reconstructed from non-live porcine liver with intact gall bladder and cystic pedicle (Figure 43). The model was mounted on a plastic grid inside a laparoscopic trainer (Simulation Trainer, AutoSuture Company, Ascot, UK). Standard laparoscopic grasper, scissors, and clip applicator (Karl Storz, Tuttlingen, Germany) were employed in the study.

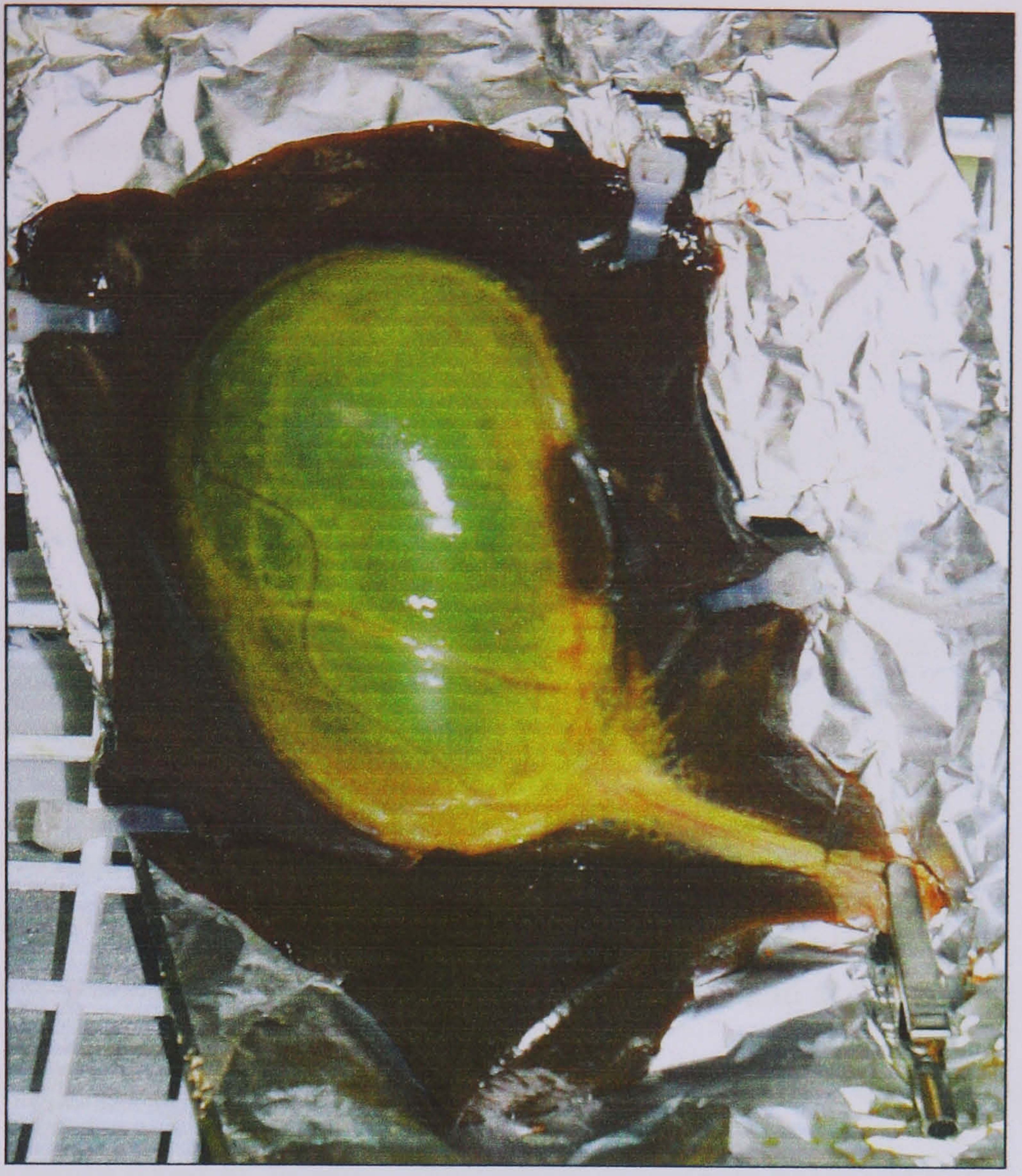

Figure 43: Gallbladder model

4.2.2.2 Subjects and practice

Six male surgeons at the Senior House Officer (SHO) level with no experience in endoscopic surgery participated in the study. The surgeons were students in The Masters in Minimal Access Surgery degree programme, Cuschieri's Skills Centre, Ninewells Hospital & Medical School, Dundee. Each subject performed two simulated laparoscopic cholecystectomies using laparoscopic grasper and scissors when they first arrived to the unit before they start their master degree programme. After 6 months of attending lectures on laparoscopic surgery and training on simulated laparoscopic tasks each subject performed another two laparoscopic cholecystectomies under the same control measures and using the same laparoscopic instruments. Six months later the subjects repeated the same procedure. Over all each subject performed six laparoscopic cholecystectomies during one year period. The experimental session for each subject was divided into: (a) time for attaching electrodes to the subjects; (b) baseline recording period (c) test period; (d) 15 minutes break between the two simulated laparoscopic cholecystectomies. Skin conductance and blinking rate were recorded continuously during each task (test period). EMG signals of the dominant hand forearm flexors, forearm extensors, biceps, triceps, and deltoid muscles were also recorded during each task.

4.2.2.3 Control measures

The monitor was placed in front of the surgeon at eye level and at a distance of one metre. The optical axis-to-target view angle was 90 degrees, with the endoscope-to-target distance being fixed at 70 mm. The camera was white balanced before each run. The endoscopic trainer was placed on a table of adjustable height so each surgeon held the grasper with the shoulder adducted the elbow at right angle, and the forearm in the horizontal plane. The experiment was conducted first thing in the morning in the same environment, illumination and under controlled room temperature. Surgeon should have slept at least 6 hours and not included in any duty the night before the day of the study.

4.2.2.4 Outcome measures

4.2.2.4.1 Mental workload measures:

- Skin conductance level (see section 2.2.2.3).
- Endogenous blinking rate (see section 2.2.2.4).

4.2.2.4.2 Muscle workload measures

- Integrated EMG (see section 2.1.2.4).

4.2.2.4.3 Performance measures

- Execution time:

The execution time was measured from the moment the surgeon grasped the handles of the scissors and grasper to the time when the instruments were released on completion of the task.

- Committed consequential errors:

Consequential error was defined as any action that resulted in a negative consequence (such as tear of the liver or perforation of gallbladder).

4.2.2.5 Statistical analysis

As the data were not normally distributed, nonparametric tests, including the Friedman's analysis of variance (ANOVA), and Wilcoxon matched-pairs signed-rank test, were used. Significant was set at the 5% level. Skin conductance level data was standardised in order to decrease the interindividual variability.

4.2.3 Results

4.2.3.1 Mental workload

Table 32 shows the median (interquartil range) of skin conductance level and blinking rate during each session. Skin Conductance Level changed significantly from the first session to the second ($p<0.05$- Wilcoxon signed ranks test) and third sessions ($p<0.05$- Wilcoxon signed ranks test) and from the second session to the third session ($p<0.05$). There was no significant change in the blinking rate with training ($p>0.05$).

Table 32: Median (IQR) blinking rate and skin conductance level during each session

Training period	Subjects	1st Session	After 6 months	After 12 months	P value*
Blinking rate	10	4.70 (3.78)	3.50 (8.65)	4.30 (3.40)	0.25
Skin conductance level (μMho)	10	10.02 (3.54)	7.51 (3.59)	6.22 (3.87)	0.007

*Friedman one-way ANOVA

4.2.3.2 Muscle workload

Table 33 shows that after 6 months of training there was no significant change in the recruitment of forearm flexors, forearm extensors, biceps, triceps, and deltoid muscles.

Table 33: Effect of training on median (IQR) integrated EMG (mv.s)

Training period	Subjects	1st Session	After 6 months	P value
Flexors	10	4.66 (5.02)	1.25 (1.43)	>0.05
Extensors	10	1.86 (4.01)	2.43 (0.97)	>0.05
Biceps	10	2.45 (3.97)	1.79 (0.65)	>0.05
Triceps	10	1.60 (4.55)	0.97 (1.29)	>0.05
Deltoid	10	0.75 (1.39)	0.97 (0.98)	>0.05

*Wilcoxon Signed Ranks test

4.2.3.3 Performance

Table 34 and figure44 show the effect of training on task execution time. There was no significant change in the task execution time between the first and second sessions (p>0.05). Median (IQR) task execution time decreased significantly during the final session 14 (7) compared to the first 32 (13) and second 19 (25) sessions (p<0.05).

Error rate decreased significantly during the second and third sessions compared to the first session (p<0.05) as shown in table 35 and figure 45. There was no significant difference between the second session and third session (p>0.05).

Table 34 : Effect of training on median (IQR) task execution time

Training period	Subjects	1st Session	After 6 months	After 12 months	P value*
Task execution time (min)	6	29.00 13.00	18.50 25.50	14.00 7.00	<0.05

* Friedman one-way ANOVA

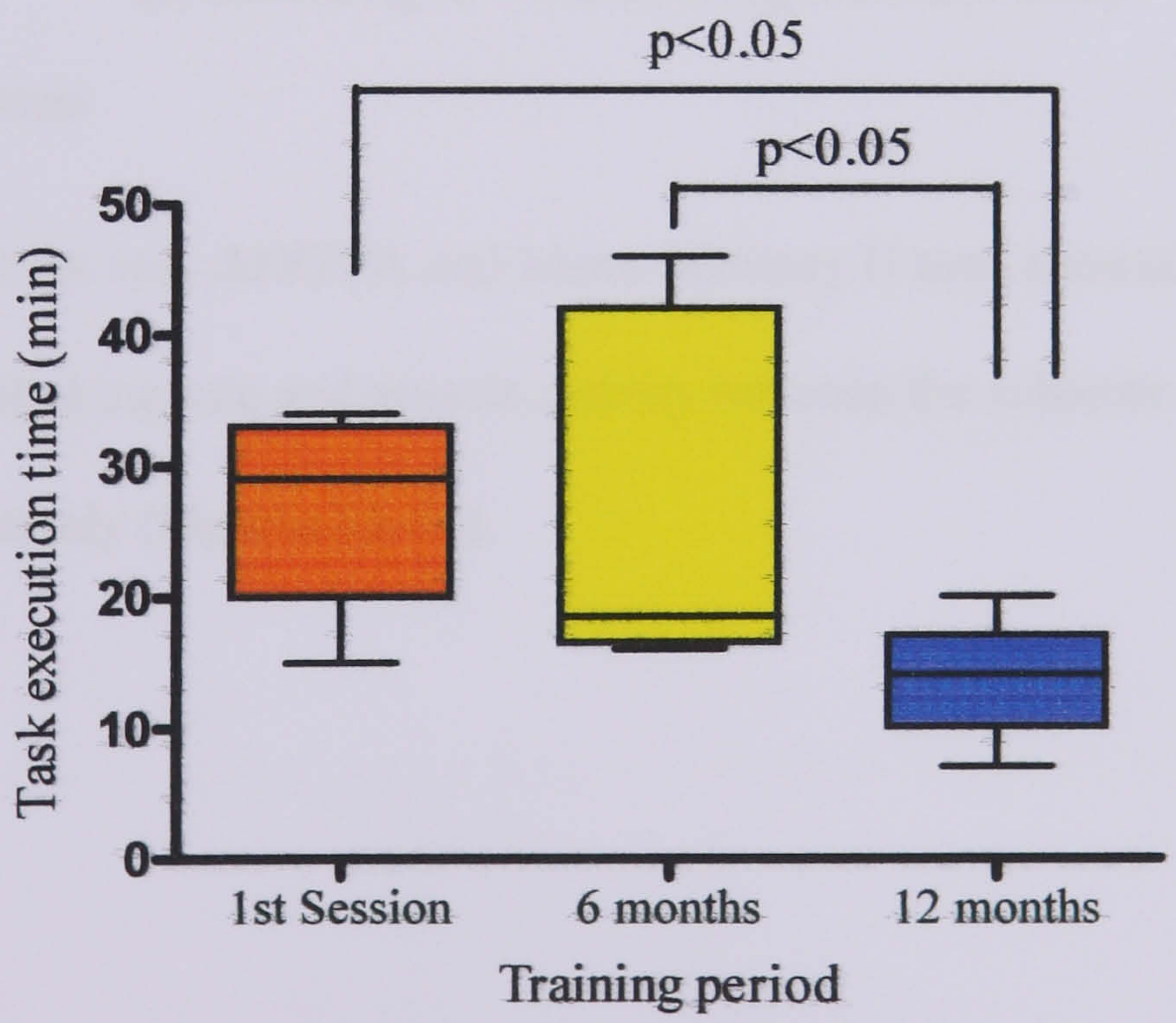

Figure 44: Effect of training on task execution time

(*p*, according to Wilcoxon Signed Rank Test)

Table 35: Effect of training on median (IQR) errors rate

Training period	Subjects	1^{st} Session	After 6 months	After 12 months	P value*
Errors rate	6	5.00 10.50	0.50 2.00	0.00 0.00	<0.05

* Friedman one-way ANOVA

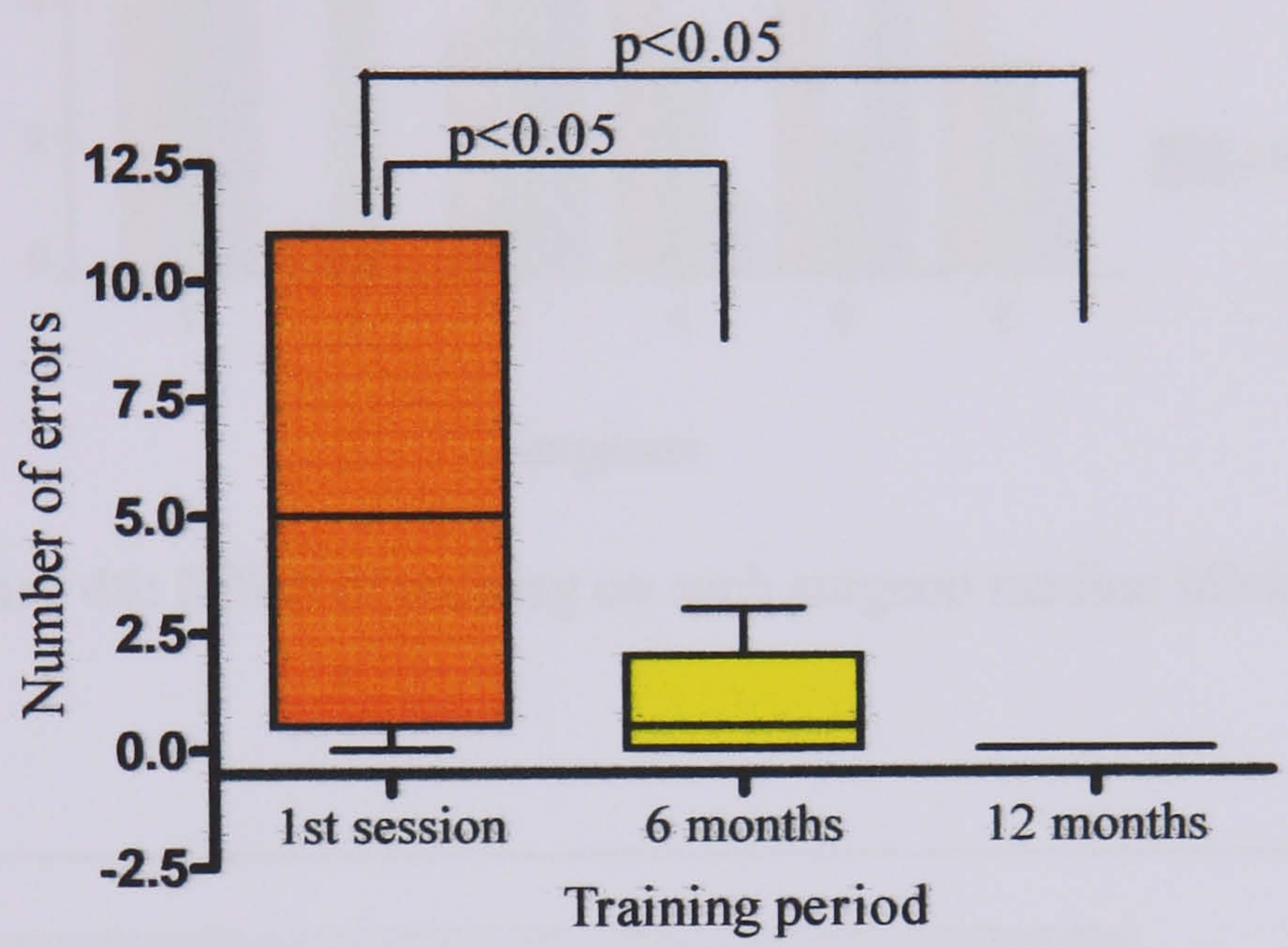

Figure 45: Effect of training on error rate

(p, according to Wilcoxon Signed Rank Test)

4.2.3.4 Surgeons

Kruskal-Wallis on way ANOVA and Mann-Whitney U tests showed no significance difference in blinking rate and muscle activity between the subjects during each session respectively (Figures 46-51).

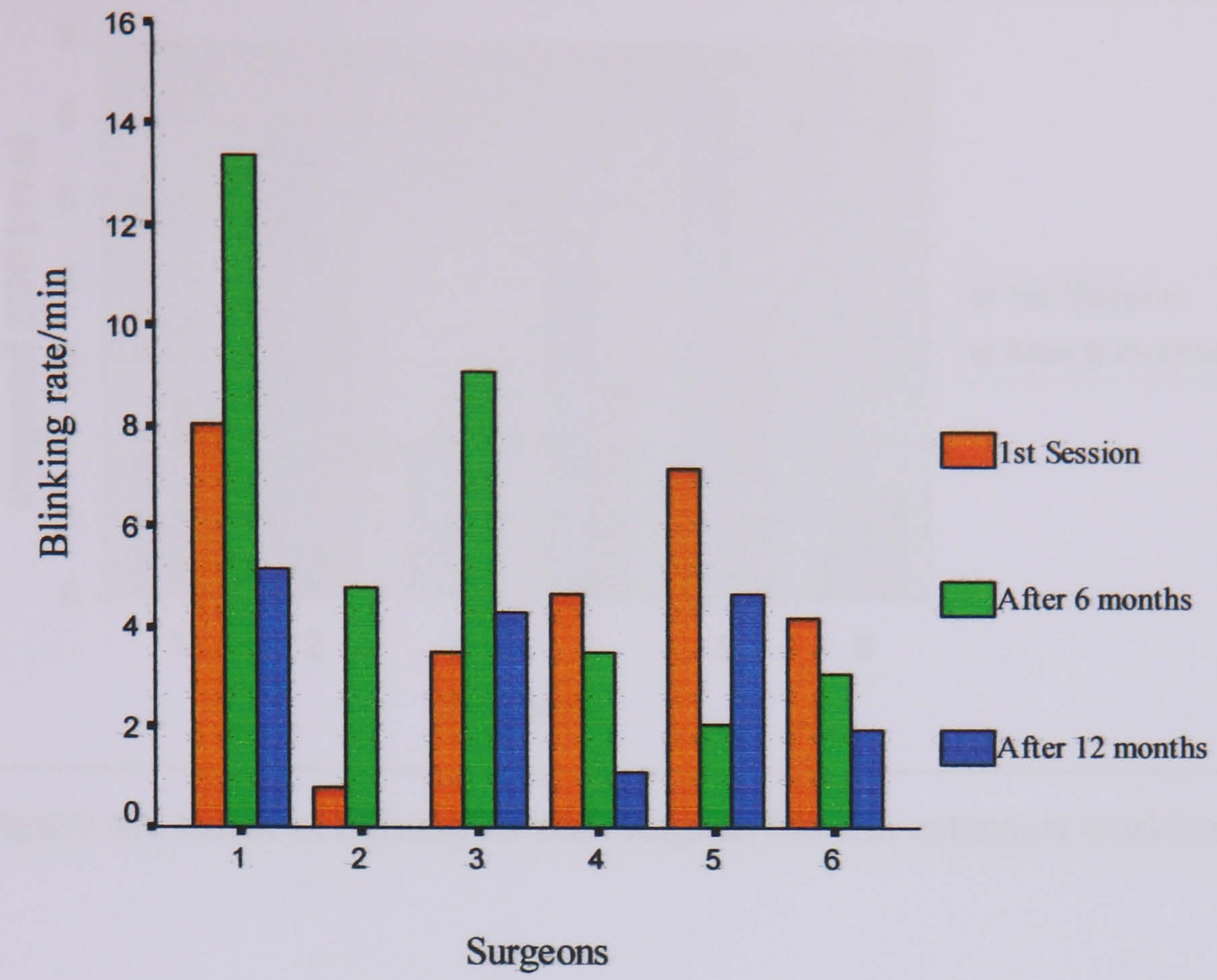

Figure 46: Effect of training on each surgeon median blinking rate

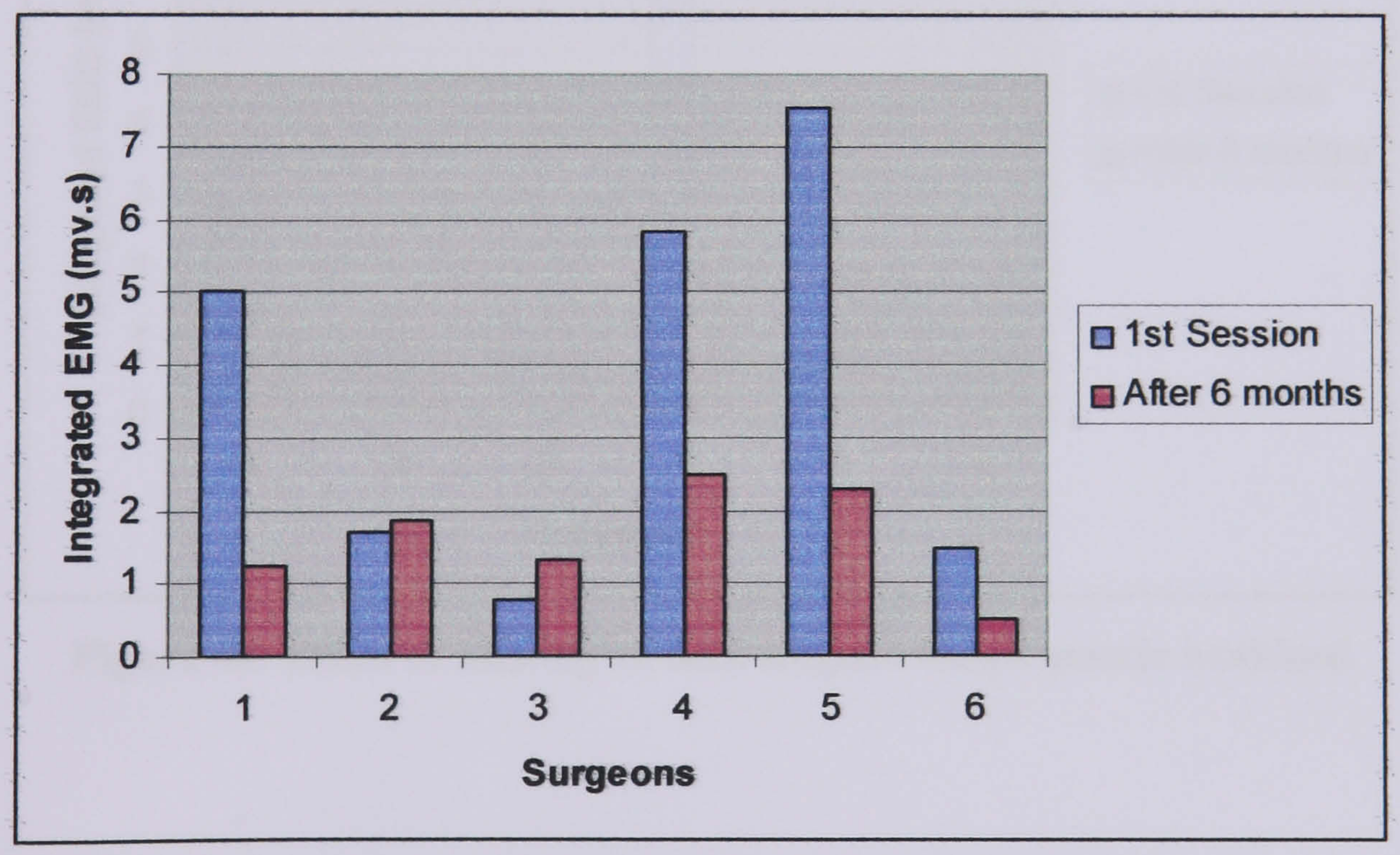

Figure 47: Effect of training on each surgeon forearm flexors workload

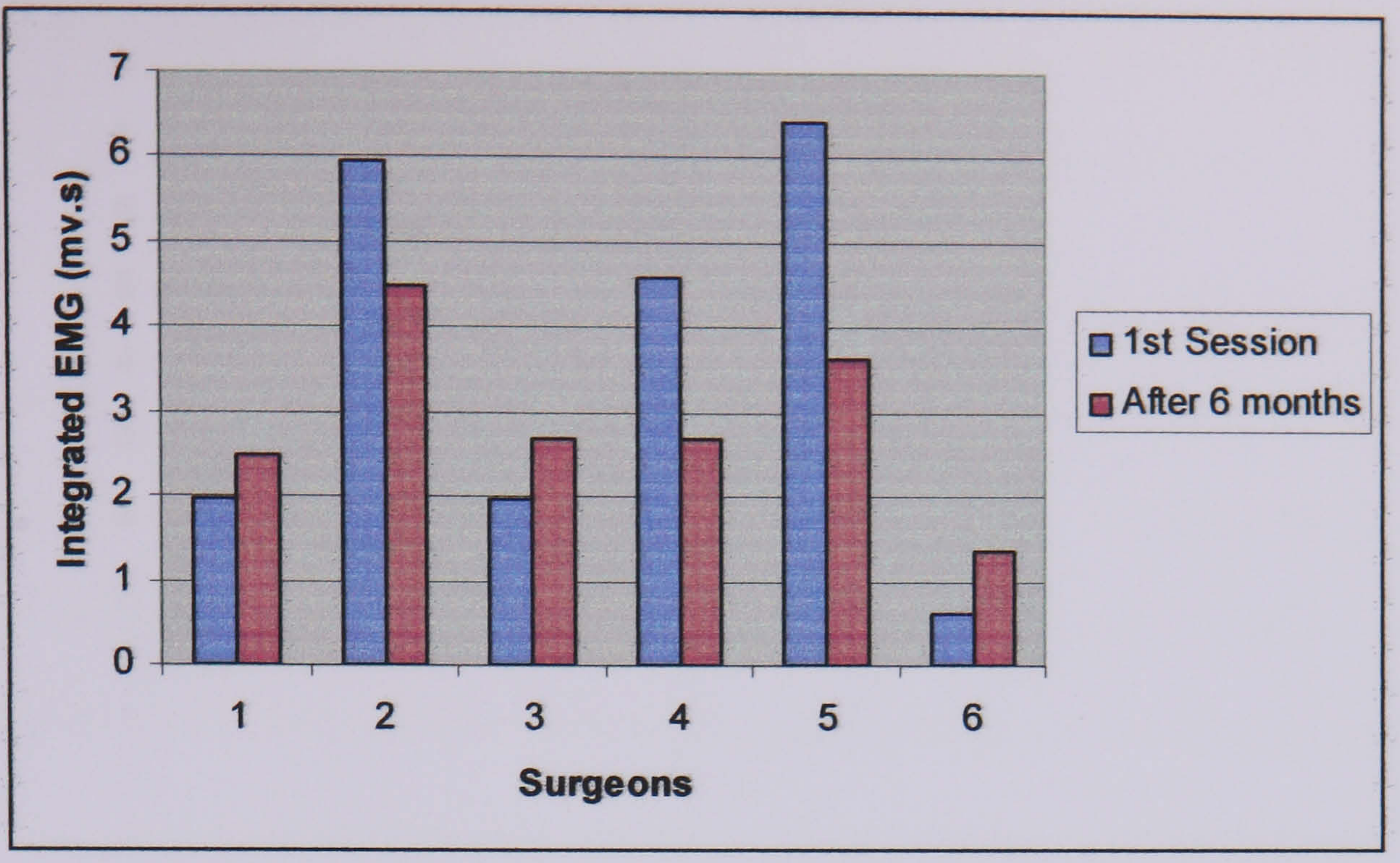

Figure 48: Effect of training on each surgeon forearm extensors workload

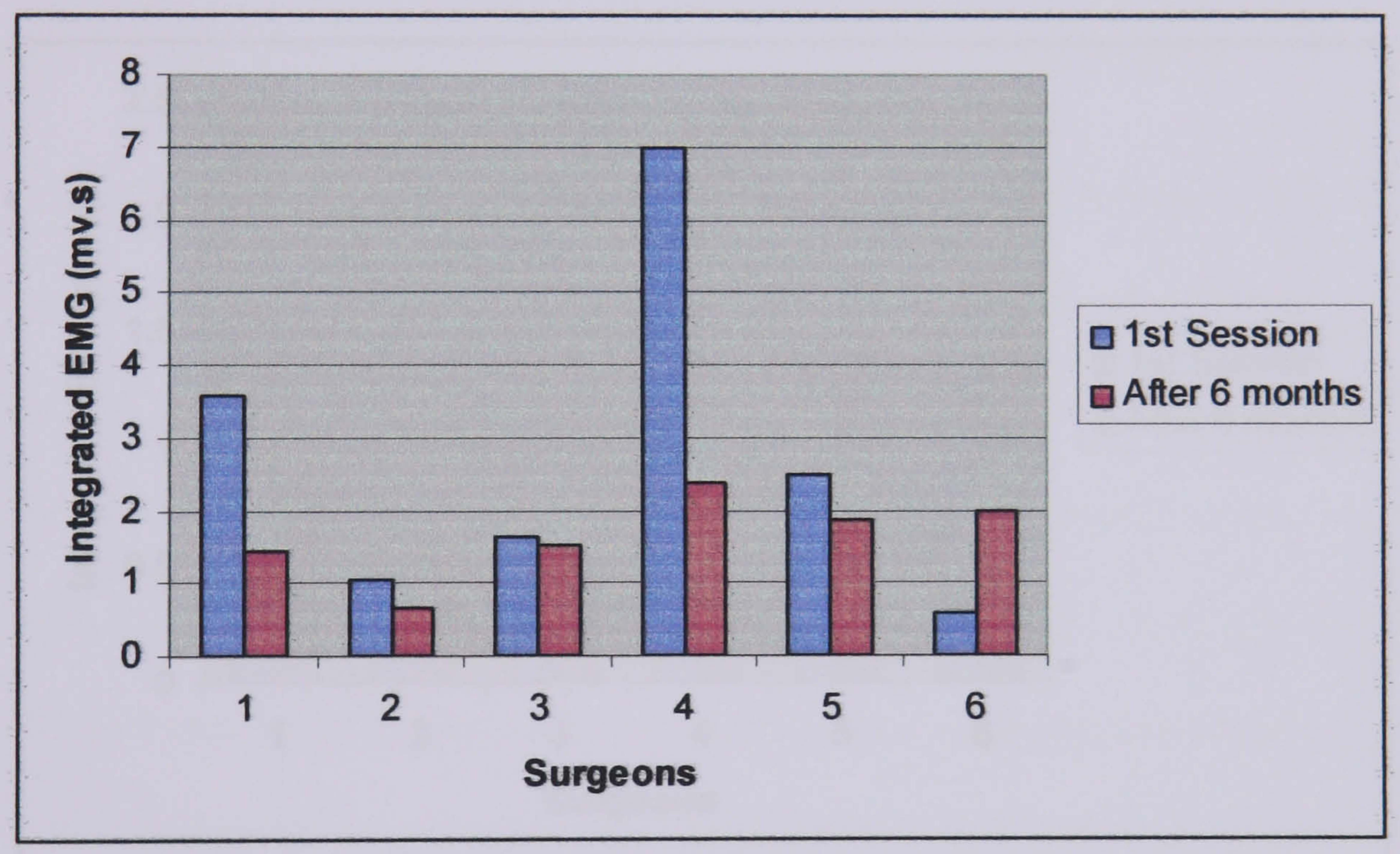

Figure 49: Effect of training on each surgeon biceps muscle workload

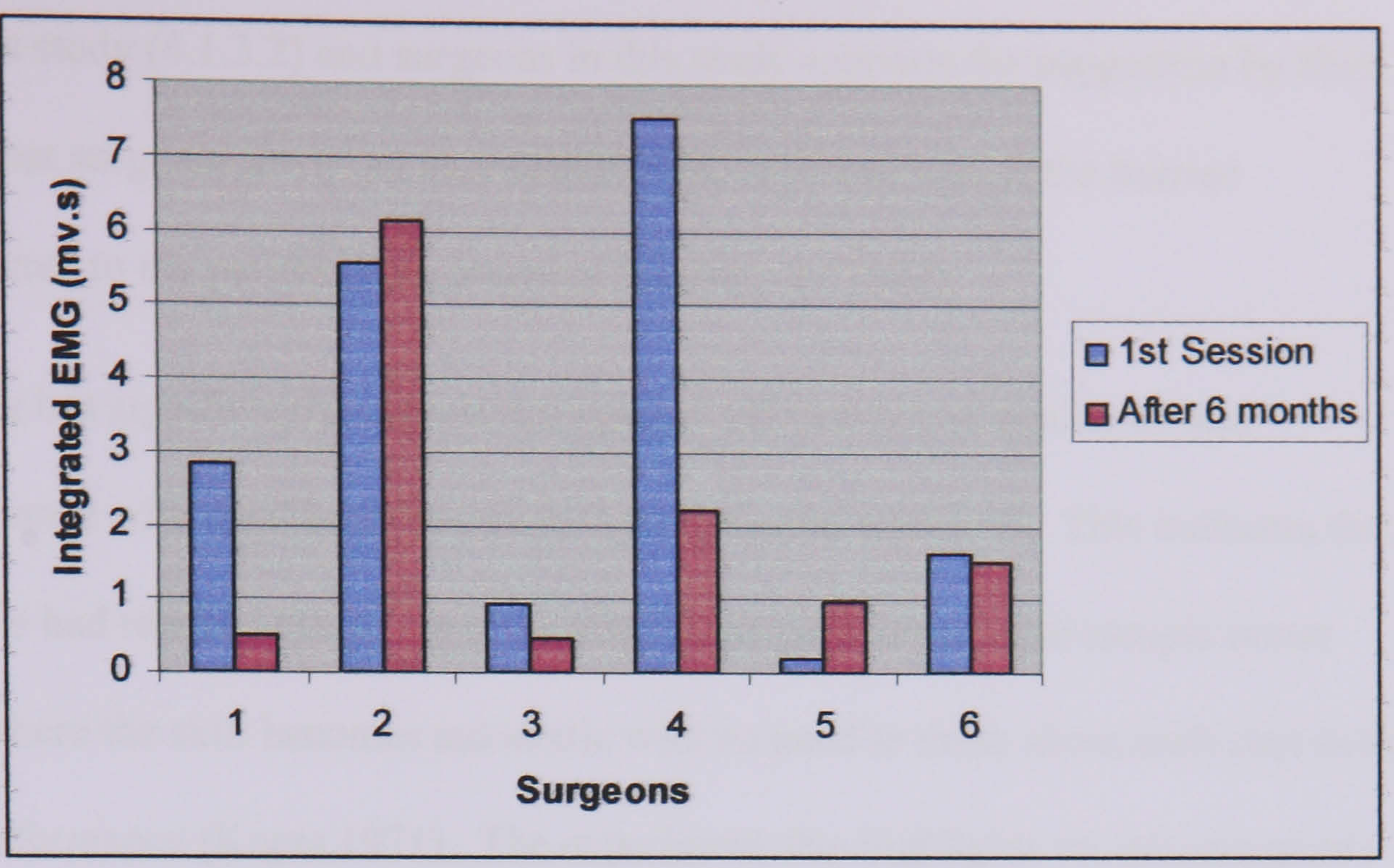

Figure 50: Effect of training on each surgeon triceps muscle workload

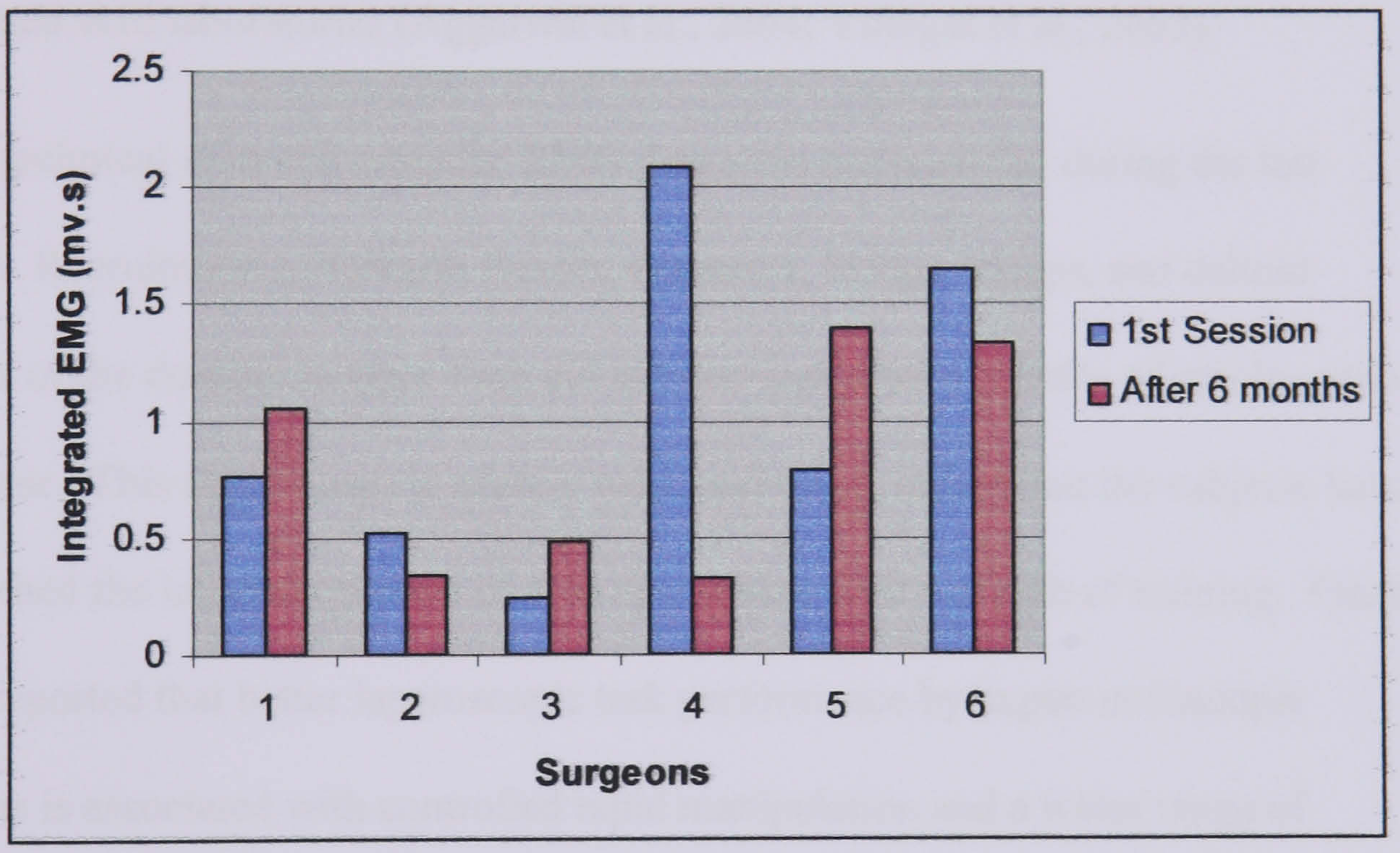

Figure 51: Effect of training on each surgeon deltoid muscle workload

4.2.4 Discussion

The study showed a significant decrease in surgeons' error rate in the second session, whereas; task execution time decrease significantly in the third session which is not in consistent with the first study. This difference in results between students in the previous study (4.1.3.2) and surgeons in this study supports the suggestion by Shah et. al., that surgeons are more concerned to the consequences of the hurried movements to the patients than students (Shah et al., 2003).

Training has significantly improved surgeons' efficiency and quality of task performance with significant decrease in their mental workload. This indicates that surgeons had reached the automation stage of acquisition of laparoscopic motor skills where the skill becomes automatic with no need to think about each step during task performance (Kopta 1971). The experiment also highlights the advantage of enrolment of surgical trainees in well-structured training programmes where experienced tutors teach the trainees component generic surgical skills within designated skill laboratories (Aggarwal et al., 2004; Villegas et al., 2003).

Due to technical error the subjects' EMG data were not recorded during the last session. Recruitment of forearm flexors, extensors, biceps, triceps, and deltoid muscles of the dominant upper limb did not decrease after 6 months of enrolment in the course. This non change in muscle workload might reflect that the subjects have not reached the integration stage of skill acquisition after 6 month of training. Emam et. al., reported that better laparoscopic task performance by expert endoscopic surgeons is associated with controlled rapid manipulation and a wider range of movement at the shoulder joint of the dominant upper limb compared to surgical trainees (Emam et al., 2000a).

4.2.5 Limitations

- Due to technical errors in EMG data collection during the third session (after 12 months), the EMG data was not included in the analysis. Therefore, we compared the EMG data during the first session and the second session only (after 6 months).

- Only 6 surgeons were included in the study. This is because there were only six students enrolled in the master course.

Conclusions

1. Training improves trainees' performance and decreases their mental workload.

2. Surgical trainees can get benefit from overlearning techniques.

CHAPTER FIVE

ANALYSIS OF MENTAL WORKLOAD DURING LAPAROSCOPIC CHOLECYSTECTOMY

5. ANALYSIS OF MENTAL WORKLOAD DURING LAPAROSCOPIC CHOLECYSTECTOMY

5.1 Objectives

Dissection of Calot's triangle is considered as the hazard zone with the higher errors rate compared to the other steps of laparoscopic cholecystectomy (Tang et al., 2004). This part of the project tests the hypothesis that dissection of Calot's triangle is the most mentally demanding step of laparoscopic cholecystectomy.

5.2 Materials and methods

5.2.1 Operative procedure

5.2.1.1 Intake and exclusion of patients

Patients recruited in the study had symptomatic gallstone disease and were admitted to the professional Unit at Tripoli Medical Centre (TMC) for elective laparoscopic cholecystectomy. Patients with acute cholecystitis or who had previous major upper abdominal surgery were excluded from the study.

Laparoscopic cholecystectomy was selected for this study because it is a common operation world wide (Soper et al., 1992), it incorporates standard laparoscopic techniques and exemplifies the complex human-machine interface during laparoscopic surgery. Hence laparoscopic cholecystectomy can be regarded as a marker laparoscopic operation such that the results of the study can be applied to a wide range of laparoscopic operations. Furthermore; laparoscopic cholecystectomy is the most frequently performed general surgical operation at the TMC, therefore; technical performance is fairly consistent from surgeon to surgeon.

External and internal video recordings were obtained out for each operation. The audio and video records of the activity of the operating team (surgeons, scrub and circulating nurse) were obtained with external video camera (Sony CCD-TR427E auto focus with a 0.5X super wide-angle lens). The camera was mounted at a height of 150 cm and at a distance of 306 cm from the foot of the operating table. This position was selected because it allowed the camera to capture any environmental factors that could influence the operating team. The external video recording started from the time of first insertion of the laparoscope and ended when the laparoscope was taken out of the abdominal cavity. The internal video recording was obtained using a SVHS videocassette recorder (JVC, Japan) for the entire operation from the time of first insertion of the laparoscope. This was done to be able to synchronise the video recording from the external camera and laparoscope during analysis. A record was also kept of the operative team (surgeon, camera operator, assistant, scrub nurse and circulating nurse) for each operation included in the study. The theatre staff were not informed about the objectives and endpoints of the study.

5.2.1.2 Surgeons

Surgeons were five consultants who had each performed at least 50 laparoscopic cholecystectomies before taking part in the study. All surgeons had normal or corrected to normal vision. The enrolled surgeons performed twenty cases of laparoscopic cholecystectomy under almost the same environmental conditions. Surgeons had at least 6 hours of sleep the night before surgery. The study was ethically approved by the Libyan Medical Society, Tripoli, Libya. Consent was obtained from each surgeon before the enrolment in the study.

5.2.1.3 Operative technique

For the purpose of the study the laparoscopic cholecystectomy was divided into four component tasks:

Task 1- Creation of pneumoperitoneum: the start of this task was timed from the insertion of the veress needle and ended by the insertion of the scope.

Task 2-Dissection of cystic duct and artery in Calot's triangle: the start of this task was timed from the moment the fundus of the gallbladder was grasped and retracted up and over the right lobe. The task ended when the cystic duct and artery had been clipped and divided.

Task 3-Separation of the gallbladder from the liver bed: this task started when the cystic artery was divided and terminated when complete separation of the gallbladder from the liver bed was achieved.

Task 4-Extraction of the gallbladder from the abdominal cavity: this task commenced at the time of gasping the detached gallbladder and ended with the complete extraction of the gallbladder from the abdominal cavity.

5.2.1.4 Grading of task difficulty

The technical difficulty of each operation was graded between 1 and 3 according to Hanna et al., (Hanna et al., 1998b):

Grade I

- No adhesions to gallbladder
- Cystic duct seen on retraction of the gallbladder
- No obvious ductal or vascular anomaly
- Unobstructed view of Callot's triangle

Grade II

- Obese patient
- Fat laden falciform
- Hypertrophied liver

  Quadrate lobe partially obstructing view and/or right hepatic lobe making retraction difficult

- Firm adhesions to the gallbladder
- Fat over Callot's triangle

Grade III

- Dense omental adhesions to gallbladder
- Duodenal adhesions to gallbladder
- Difficult, obscure, abnormal anatomy
- Contracted, inflamed or densely adherent gallbladder
- Stone is impacted in the neck/Harman's pouch
- Gallbladder neck is adherent to bile duct

5.2.2 Mental workload assessment apparatus

Heart rate (HR) and heart rate variability analysis (HRV) were used as methods of evaluating mental workload in this study. Heart Rhythm Scanner system (Biocom Technologies, Washington, USA) was used for measuring and evaluating heart and heart rate variability (HRV). For the ECG recording, three self-adhesive surface circular electrodes (Red Dot, 2239; 3M Health Care, Postfach, Germany), each of 60-mm diameter, were used. One electrode was placed below the jugular notch and a second electrode between the ninth and tenth rib on the left side of the rib cage. A common ground electrode was placed between the ninth and tenth rib on the right side of the rib cage. The electrodes were connected to the active ECG unit which was fixed to the surgeon's green suit (trouser). The active ECG unit was connected to a laptop computer containing the Heart Rhythm Scanner software version 2 through a cable with 2 metre length. Heart rate and heart rate variability were recorded continuously during each of the four tasks of the operation. A research fellow starts the recording of the ECG activity by pressing a button displayed on the monitor of the laptop at the beginning of the task; and ends the recording by pressing another button at the end of the task. The data were saved directly to the computer hard disc. Heart rate and heart rate variability measures for each surgeon were recorded preoperatively for 5 minutes as a baseline.

5.2.3 Endpoints

- Heart Rate (For further details of HR and HRV see section 2.1.2.5);
- Heart Rate Variability (Lfn, Hfn, Lfn/Hfn);
- Committed consequential errors: Consequential error was defined as any action that resulted in a negative consequence (such as bleeding from the artery, improper clipping of cystic duct with bile leak, improper clipping of cystic artery with bleeding, perforation of gallbladder, or liver injury). The recorded video tapes from the laparoscopic camera were analysed to obtain the committed consequential errors rate.

5.2.4 Statistical analysis

Heart rate and heart rate variability data were standardised (Backs et al., 1994; Meijman TF 1997; Vicente et al., 1987). Each subject's log-transformed value during the task was subtracted from his log-transformed one of the baseline period

(Meijman TF 1997). Repeated measures ANOVA analysis was carried out. The analysis had one factor (task) with four levels (all operation tasks). The differences between the four operation tasks (creation of pneumoperitoneum, dissection of cystic duct and artery, dissection of gallbladder from liver bed, and extraction of gallbladder) were examined using t-test with Bonferroni correction. Results of the committed consequential errors during dissection of calot's triangle and gallbladder were normally distributed. Therefore; paired sample t-test was used for the analysis of error rate. The Statistical Package for Social Sciences (SPSS) was used for the analysis, and significance was set at the 5% level. Only five surgeons with the same level of laparoscopic surgery were enrolled in the study in order to minimise inter-individual variations.

5.3 Results

The same pattern of responding was found for the twenty replications of heart rate and heart rate variability data. There were no statistically significant differences in the heart rate and heart rate variability data between surgeons across the four tasks. The effect of case difficulty on HR and HRV measures was not studied because almost all the cases were graded as grade II.

5.3.1 Heart rate

The mean (95% confidence intervals) heart rate (beats/min) was 94.12 (92.93-95.37), 114.66 (112.26-117.30), 110.67 (107.53-114.24), 103.78 (99.69-108.75) during creation of pneumoperitoneum, dissection of Calot's triangle, dissection of gallbladder from liver bed, and extraction of gallbladder respectively. There was a significant difference in HR across the laparoscopic cholecystectomy tasks [F (3, 57) = 87.64, p<0.01].

Heart rate increased significantly during dissection of Calot's triangle, dissection of gallbladder, and extraction of gallbladder tasks compared to the creation of pneumoperitoneum task (p<0.01). Dissection of Calot's triangle task showed the highest HR reading compared to the dissection (p<0.05) and extraction (p<0.01) of gallbladder tasks. Heart rate was higher during dissection of gallbladder from the liver bed than during extraction of gallbladder from the abdominal cavity (p<0.05).

5.3.2 Heart rate variability

5.3.2.1 Normalised low frequency (Lfn)

The mean (95% confidence intervals) of Lfn was 80.66 (76.35-87.97), 73.02 (64.72-75.09), 67.96 (61.09-72.10), 67.90 (60.51-79.814) during creation of pneumoperitoneum, dissection of Calot's triangle, dissection of gallbladder from liver bed, and extraction of gallbladder respectively. There was a significant difference in Lfn across the laparoscopic cholecystectomy tasks [F (3, 45) = 87.64, p<0.01].

There was a significant suppression in the low frequency band (Lfn) during dissection of Calot's triangle and dissection of gallbladder compared to the creation of pneumoperitoneum (p<0.05). However Lfn did not change significantly during extraction of gallbladder compared to the creation of pneumoperitoneum (p>0.05). There was no significant change in Lfn across dissection of Calot's triangle, dissection of gallbladder and extraction of gallbladder tasks (p>0.05).

5.3.2.2 Normalised high frequency (Hfn)

Mean (95% confidence intervals) Hfn was 15.34 (12.80-22.60), 21.93 (19.27-30.80), 28.88 (25.64-34.93), 28.16 (27.09-58.71) during creation of pneumoperitoneum, dissection of Calot's triangle, dissection of gallbladder from liver bed, and extraction of gallbladder respectively. There was a significant difference in Hfn across the laparoscopic cholecystectomy tasks [$F(3, 57) = 3.82$, $p<0.05$].

The high frequency band changed significantly during dissection of gallbladder task compared to the pneumoperitoneum task ($p<0.01$), whereas; Hfn did not change significantly during dissection of Calot's triangle and extraction of gallbladder tasks compared to pneumoperitoneum task ($p>0.05$). This band did not show any significant change across dissection of Calot's triangle, dissection of gallbladder, and extraction of gallbladder tasks ($p>0.05$).

5.3.2.3 Low frequency/High frequency (Lf/Hf)

Mean (95% confidence intervals) Lf/Hf was 4.642 (12.80-22.60), 2.69 (19.27-30.80), 1.67 (25.64-34.93), 2.05 (27.09-58.71) during creation of pneumoperitoneum, dissection of Calot's triangle, dissection of gallbladder from liver bed, and extraction of gallbladder respectively. There was a significant difference in Lf/Hf across the laparoscopic cholecystectomy tasks [$F(3, 54) = 4.61$, $p<0.05$].

The Lf/Hf changed significantly during dissection of gallbladder task compared to the pneumoperitoneum task ($p<0.01$), whereas; there was no significant change in Lf/Hf during dissection of Calot's triangle and extraction of gallbladder tasks compared to the creation of pneumoperitoneum task ($p>0.05$). There was no significant change in Lf/Hf across dissection of Calot's triangle, dissection of gallbladder, and extraction of gallbladder tasks ($p>0.05$).

5.3.3 Committed consequential errors

Figure 52 shows the consequential errors rate during dissection of Calot's triangle and gallbladder. Surgeons committed more errors during dissection of Calot's triangle compared to the dissection of gallbladder from the liver bed ($p<0.01$).

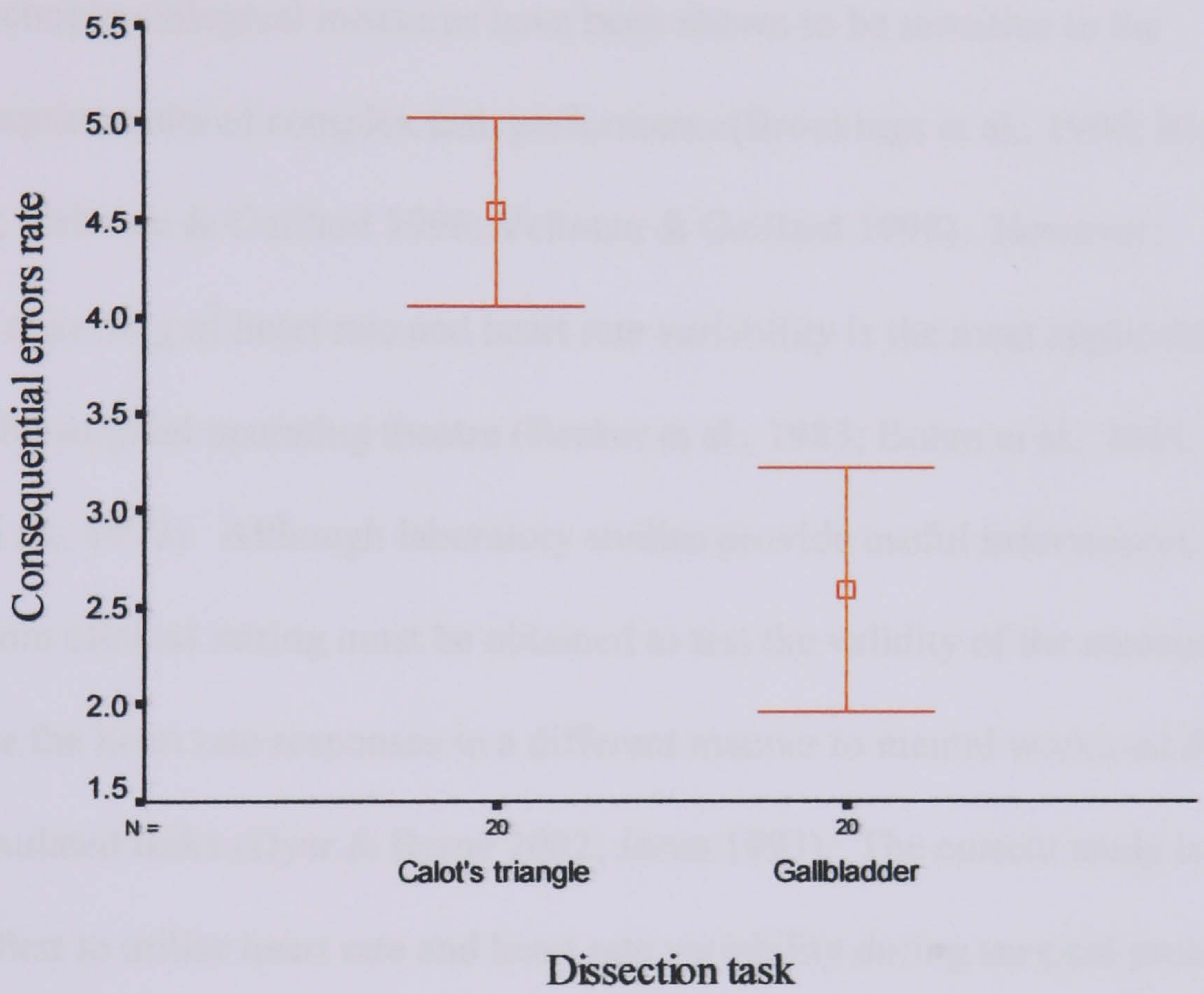

Figure 52: Mean (95% CI) of consequential errors rate during dissection of Calot's triangle and gallbladder

5.4 Discussion

Laparoscopic surgery can place significant demands on the surgeon's cognitive capabilities. High levels of cognitive demands can lead to errors with potential catastrophic outcome. Increasing our knowledge of the effects of the various demand levels encountered during laparoscopic task performance is necessary to design systems and develop training regimens and operating procedures that will reduce cognitive demands so they do not exceed the capacities of the operating team. Data from various laparoscopic procedures will help in the understanding of the usual demands placed on operating team and present a reference point to compare data obtained from unusual circumstances. This requires measures that are sensitive to cognitive workload so that one can assess the effects of procedure demands on the surgeon.

Several psychophysiological measures have been shown to be sensitive to the cognitive requirements of complex task performance(Brookings et al., 1996; Richter et al., 1998; Veltman & Gaillard 1996; Veltman & Gaillard 1998). However; continuous recording of heart rate and heart rate variability is the most applicable method in the surgical operating theatre (Becker et al., 1983; Bohm et al., 2001; Goldman et al., 1972). Although laboratory studies provide useful information, data collected from clinical setting must be obtained to test the validity of the measures. Furthermore the heart rate responses in a different manner to mental workload during real and simulated tasks (Dyer & Byrne 2002; Jorna 1993). The current study is among the first to utilise heart rate and heart rate variability during surgical procedure in the clinical setting.

Heart rate and heart rate variability responses for each surgeon were essentially identical across the same task of laparoscopic cholecystectomy. The results of this investigation demonstrate that heart rate and heart rate variability recorded during laparoscopic cholecystectomy produce patterns of activity that are consistent over a period of weeks. This indicates that those measures are highly reliable over time among the same surgeon.

Heart rate exhibited changes in response to the various demands of the operations. Heart rate variability was less sensitive than heart rate. The highest heart rate occurred during dissection of cystic duct and artery followed by dissection of gallbladder from liver bed. The lowest intraoperative surgeons' heart rate was found during the creation of pneumoperitoneum followed by extraction of gallbladder from the abdominal cavity. The results on heart rate variability showed statistically significant decreased variability for low band (Lfn) only during the dissection of cystic duct and artery, and dissection of gallbladder compared to creation of pneumoperitoneum. Therefore, identification of cystic duct and artery and dissection of gallbladder from the liver bed produced the greatest number of changes in the heart rate and heart rate variability data. Those results highlight the increased level of cognitive demand placed on the surgeons during these important manoeuvres. Finding that tasks with lower cognitive demands, such as extraction of gallbladder from the abdominal cavity, associated with low changes in heart rate and heart rate variability data further supports this view. However, heart rate was more sensitive than heart rate variability in response to the demands placed on the surgeons by different operative steps. This is because heart rate variability is sensitive only to the large changes in task difficulty (Jorna 1992; Veltman & Gaillard 1998). Furthermore; there were no significant changes in the higher band (Hfn) and Lfn/Hfn. Error rate was higher during dissection of Calot's triangle compared to dissection of gallbladder from liver bed which is in consistency with the reported series on the assessment of errors enacted during 200 laparoscopic cholecystectomy using human reliability analysis techniques (Tang et al., 2004). Dissection of calot's triangle is considered as the high risk zone during laparoscopic cholecystectomy (Tang et al., 2004). The increase in errors rate along with the increase in heart rate and suppression of the low frequency band of HRV indicate that dissection of calot's triangle is high mentally demanding step of cholecystectomy.

Because of the continuous nature of the Hear Rate and Heart Rate Variability data it may be possible to develop systems which provide on-line monitoring of mental workload that can provide feedback to the surgeons which can help in training and reduction of commencement of errors during laparoscopic surgery.

5.5 Conclusions

1. Heart rate was more sensitive to the small changes in task difficulty than heart rate variability.
2. Heart rate variability was sensitive only to the large changes in task difficulty.
3. Dissection of Calot's triangle is the most mentally demanding stage of laparoscopic cholecystectomy.
4. Error rate was higher during dissection of Calot's triangle compared to dissection of gallbladder from liver bed.

CHAPTER SIX

SUMMARY AND FUTURE WORK

6. SUMMARY AND FUTURE WORK

6.1 Summary

Several performance shaping factors can affect laparoscopic task performance. However, because of the time frame and budget of this project only four factors were studied; operating room layout, imaging system modality, training, and task difficulty. The main hypothesis of the project was that improving the currently available operating room lay out, image processing systems, and surgeons' training can decrease surgeon's workload and improve their performance.

The laboratory based part of the project studied the effect of image display unit placement, imaging modality and training on physical and mental workload in volunteer subjects as they are performing simulated surgical tasks using laparoscopic techniques. The clinical part of the project was carried out in the operating theatre to investigate the effect of different steps of real laparoscopic cholecystectomy on surgeon's mental workload. Subjects' physical workload during task performance was measured using an electromyogram and postural angles. Mental workload was studied by analysing subjects' heart rate and heart rate variability, electrodermal activity and endogenous eye blinking rate.

Chapter one of the theses reviewed the literature on laparoscopic task performance shaping factors and mental and physical workload measures. In chapter two, the aim was to investigating the effect of imaging related task set up on surgeon's mental workload, physical workload and performance. The results showed that 20-inch (large) image was superior to the 14-inch (small) image. The best location for the small image was at 100 cm viewing distance, whereas; for the large image ranged from 60 cm to 100 cm viewing distance. Placing the image display location at the operating field level improved surgeons' performance and decreased their mental and physical workload level.

Chapter 3 investigated the effect of imaging modality as a performance-shaping factor on surgeon's mental workload. Task efficiency for surgeons with no experience in laparoscopic surgery was degraded with the use of video endoscopic imaging systems compared to normal vision. There was no improvement in endoscopic task performance on using Zeiss Medilive 3-D video system as three dimensional video endoscopic imaging compared to using it as two dimensional system. The non-laparoscopic surgeons experienced more mental workload on using either two-dimensional or three-dimensional endoscopic imaging systems compared to normal vision. The two dimensional display for Zeiss Medilive 3-D video system caused less mental workload compared to three dimensional display of the same system.

The fourth chapter investigated the effect of innate ability and training on surgeon's mental and physical workload. Basic laparoscopic skills improve with task repetition in a brief laboratory training course. Training improves trainees' performance and decreases their mental workload. The context of residency curriculum should take in consideration the effect of subject's innate ability on the acquisition of laparoscopic skills.

Finally, in chapter 5, the aim was to study the effect of task difficulty on surgeon's mental workload during clinical laparoscopic cholecystectomy. Heart rate was more sensitive to the small changes in task difficulty than heart rate variability. Heart rate variability was sensitive only to the large changes in task difficulty. Dissection of Calot's triangle is the most mentally demanding stage of laparoscopic cholecystectomy. Errors rate was higher during dissection of Calot's triangle compared to dissection of gallbladder from liver bed.

6.2 Future work

Further ergonomic studies that could be done in laparoscopic surgery:

- The effect of improving laparoscopic imaging and mechanical constraints on surgeon's mental and physical workload. This can have implication in laparoscopic instruments design.
- The use of mental workload measures as an index of automaticity level during skill acquisition.
- The influence of operating team coordination and experience on their mental workload in the operating room.
- Coping strategies of the operating team with increased mental working load.
- Setting up standard and safety working hour regulations based on expected mental working load for different procedures in order to maintain patient's safety.

REFERENCES

7. REFERENCES

- Aasman, J., Mulder, G., & Mulder, L. J. 1987, "Operator effort and the measurement of heart-rate variability", *Hum.Factors*, vol. 29, no. 2, pp. 161-170.

- Ackerman, P. L., Beier, M. E., & Boyle, M. O. 1988, "Determinants of individual differences during skill acquisition: cognitive abilities and information processing.", *J Exp.Psychol.Gen.*, vol. 117, pp. 288-318.

- Aggarwal, R., Moorthy, K., & Darzi, A. 2004, "Laparoscopic skills training and assessment", *Br.J Surg.*, vol. 91, no. 12, pp. 1549-1558.

- Ahmed, S., Hanna, G. B., & Cuschieri, A. 2004, "Optimal angle between instrument shaft and handle for laparoscopic bowel suturing", *Arch.Surg*, vol. 139, no. 1, pp. 89-92.

- Altschuler, E. L. 1999, "Prospective, randomised trial of sleep deprived versus rested surgeons", *Lancet*, vol. 353, no. 9151, p. 501.

- Anastakis, D. J., Hamstra, S. J., & Matsumoto, E. D. 2000, "Visual-spatial abilities in surgical training", *Am.J Surg.*, vol. 179, no. 6, pp. 469-471.

- Anastakis, D. J., Regehr, G., Reznick, R. K., Cusimano, M., Murnaghan, J., Brown, M., & Hutchison, C. 1999, "Assessment of technical skills transfer from the bench training model to the human model", *Am.J Surg.*, vol. 177, no. 2, pp. 167-170.

- Andrews, L. B., Stocking, C., Krizek, T., Gottlieb, L., Krizek, C., Vargish, T., & Siegler, M. 1997, "An alternative strategy for studying adverse events in medical care", *Lancet*, vol. 349, no. 9048, pp. 309-313.

- Ankrum, D. R. & Nemeth, K. J. 1995, "Posture, comfort and monitor placement.", *Ergon Des*, vol. 3, pp. 7-9.

- Backs, R. W., Ryan, A. M., & Wilson, G. F. 1994, "Psychophysiological measures of workload during continuous manual performance", *Hum.Factors*, vol. 36, no. 3, pp. 514-531.

- Backs, R. W. & Walrath, L. C. 1992, "Eye movement and pupillary response indices of mental workload during visual search of symbolic displays", *Appl Ergon.*, vol. 23, no. 4, pp. 243-254.

- Bainbridge, L. 1997, "The Change in Concepts Needed to Account for Human Behavior in Complex Dynamic Tasks", *IEEE TRANSACTIONS ON SYSTEMS, MAN, AND CYBERNETICS-PART A: SYSTEMS AND HUMANS*, vol. 27, no. 3, pp. 351-359.

- Baker, J. T., Donoghue, J. P., & Sanes, J. N. 1999, "Gaze direction modulates finger movement activation patterns in human cerebral cortex", *J Neurosci.*, vol. 19, no. 22, pp. 10044-10052.

- Bauer, L. O., Goldstein, R., & Stern, J. A. 1987, "Effects of information-processing demands on physiological response patterns", *Hum.Factors*, vol. 29, no. 2, pp. 213-234.

- Becker, W. G. E., Ellis, H., Goldsmith, R., & Kaye, A. M. 1983, "Heart rates of surgeons in theatre", *Ergonomics*, vol. 26, pp. 803-807.
- Berci, G. & Paz-Partlow, M. 1988, "Electronic imaging in endoscopy", *Surg.Endosc.*, vol. 2, no. 4, pp. 227-233.
- Berguer, R. 1998, "Surgical technology and the ergonomics of laparoscopic instruments", *Surg.Endosc.*, vol. 12, no. 5, pp. 458-462.
- Berguer, R., Forkey, D. L., & Smith, W. D. 1999, "Ergonomic problems associated with laparoscopic surgery", *Surg.Endosc.*, vol. 13, no. 5, pp. 466-468.
- Berguer, R., Forkey, D. L., & Smith, W. D. 2001a, "The effect of laparoscopic instrument working angle on surgeons' upper extremity workload", *Surg.Endosc.*, vol. 15, no. 9, pp. 1027-1029.
- Berguer, R., Gerber, S., Kilpatrick, G., & Beckley, D. 1998, "An ergonomic comparison of in-line vs pistol-grip handle configuration in a laparoscopic grasper", *Surg.Endosc.*, vol. 12, no. 6, pp. 805-808.
- Berguer, R., Rab, G. T., Abu-Ghaida, H., Alarcon, A., & Chung, J. 1997, "A comparison of surgeons' posture during laparoscopic and open surgical procedures", *Surg.Endosc.*, vol. 11, no. 2, pp. 139-142.
- Berguer, R., Smith, W. D., & Chung, Y. H. 2001c, "Performing laparoscopic surgery is significantly more stressful for the surgeon than open surgery", *Surg.Endosc.*, vol. 15, no. 10, pp. 1204-1207.

- Berguer, R., Smith, W. D., & Chung, Y. H. 2001b, "Performing laparoscopic surgery is significantly more stressful for the surgeon than open surgery", *Surg.Endosc.*, vol. 15, no. 10, pp. 1204-1207.
- Berntson, G. G., Bigger, J. T., Jr., Eckberg, D. L., Grossman, P., Kaufmann, P. G., Malik, M., Nagaraja, H. N., Porges, S. W., Saul, J. P., Stone, P. H., & van der Molen, M. W. 1997, "Heart rate variability: origins, methods, and interpretive caveats", *Psychophysiology*, vol. 34, no. 6, pp. 623-648.
- Berquer, R., Smith, W. D., & Davis, S. 2002, "An ergonomic study of the optimum operating table height for laparoscopic surgery", *Surg.Endosc.*, vol. 16, no. 3, pp. 416-421.
- Bessell, J. R., Flemming E, & Kunert W 1996, "Maintenanace of clear vision during laparoscopy", *Min Invas Ther & Allied Technol*, vol. 5, pp. 450-455.
- Bhatnager, V., Drury, C. G., & Schiro, S. G. 1985, "Posture, postural discomfort, and performance", *Hum.Factors*, vol. 27, no. 2, pp. 189-199.
- Blythe, J., Baumann, A., & Giovannetti, P. 2001, "Nurses' experiences of restructuring in three Ontario hospitals", *J Nurs.Scholarsh.*, vol. 33, no. 1, pp. 61-68.
- Bohm, B., Rotting, N., Schwenk, W., Grebe, S., & Mansmann, U. 2001, "A prospective randomized trial on heart rate variability of the surgical team during laparoscopic and conventional sigmoid resection", *Arch.Surg.*, vol. 136, no. 3, pp. 305-310.

- Boppart, S. A., Deutsch, T. F., & Rattner, D. W. 1999, "Optical imaging technology in minimally invasive surgery. Current status and future directions", *Surg.Endosc.*, vol. 13, no. 7, pp. 718-722.
- Brookings, J. B., Wilson, G. F., & Swain, C. R. 1996, "Psychophysiological responses to changes in workload during simulated air traffic control", *Biol.Psychol.*, vol. 42, no. 3, pp. 361-377.
- Burdorf, A. & van der Beek, A. J. 1999, "In musculoskeletal epidemiology are we asking the unanswerable in questionnaires on physical load?", *Scand.J Work Environ.Health*, vol. 25, no. 2, pp. 81-83.
- Burgess-Limerick, R., Mon-Williams, M., & Coppard, V. L. 2000, "Visual display height", *Hum.Factors*, vol. 42, no. 1, pp. 140-150.
- Burgess-Limerick, R., Plooy, A., & Ankrum, D. R. 1998, "The effect of imposed and self-selected computer monitor height on posture and gaze angle", *Clin.Biomech.(Bristol., Avon.)*, vol. 13, no. 8, pp. 584-592.
- Cabrera, I. N. & Lee, M. H. 2000, "Reducing noise pollution in the hospital setting by establishing a department of sound: a survey of recent research on the effects of noise and music in health care", *Prev.Med.*, vol. 30, no. 4, pp. 339-345.
- Cao, C. G., MacKenzie, C. L., Ibbotson, J. A., Turner, L. J., Blair, N. P., & Nagy, A. G. 1999a, "Hierarchical decomposition of laparoscopic procedures", *Stud.Health Technol.Inform.*, vol. 62, pp. 83-89.

- Cao, C. G., Mackenzie, C. L., Ibbotson, J. A., Turner, L. J., Blair, N. P., & Nagy, A. G. 1999b, "Hierarchical decomposition of laparoscopic procedures", *Stud.Health Technol Inform.*, vol. 62, pp. 83-89.

- Carswell, C. M., Clarke, D., & Seales, W. B. 2005, "Assessing mental workload during laparoscopic surgery", *Surg Innov.*, vol. 12, no. 1, pp. 80-90.

- Chan, A. C., Chung, S. C., Yim, A. P., Lau, J. Y., Ng, E. K., & Li, A. K. 1997, "Comparison of two-dimensional vs three-dimensional camera systems in laparoscopic surgery", *Surg.Endosc.*, vol. 11, no. 5, pp. 438-440.

- Classen, M., Knyrim, K., Seidlitz, H. K., & Hagenmuller, F. 1987, "Electronic endoscopy--the latest technology", *Endoscopy*, vol. 19, no. 3, pp. 118-123.

- Coleman, J., Nduka, C. C., & Darzi, A. 1994, "Virtual reality and laparoscopic surgery", *Br.J Surg.*, vol. 81, no. 12, pp. 1709-1711.

- Congleton, J. J., Ayoub, M. M., & Smith, J. L. 1985, "The design and evaluation of the neutral posture chair for surgeons", *Hum.Factors*, vol. 27, no. 5, pp. 589-600.

- Cooke, N. J., Salas, E., Cannon-Bowers, J. A., & Stout, R. J. 2000, "Measuring team knowledge", *Hum.Factors*, vol. 42, no. 1, pp. 151-173.

- Corlett, E. N. & Bishop, R. P. 1976, "A technique for assessing postural discomfort", *Ergonomics*, vol. 19, no. 2, pp. 175-182.

- Crosthwaite, G., Chung, T., Dunkley, P., Shimi, S., & Cuschieri, A. 1995b, "Comparison of direct vision and electronic two- and three-dimensional display systems on surgical task efficiency in endoscopic surgery", *Br.J Surg.*, vol. 82, no. 6, pp. 849-851.

- Crosthwaite, G., Chung, T., Dunkley, P., Shimi, S., & Cuschieri, A. 1995a, "Comparison of direct vision and electronic two- and three-dimensional display systems on surgical task efficiency in endoscopic surgery", *Br.J Surg*, vol. 82, no. 6, pp. 849-851.

- Crothers, I. R., Gallagher, A. G., McClure, N., James, D. T., & McGuigan, J. 1999, "Experienced laparoscopic surgeons are automated to the "fulcrum effect": an ergonomic demonstration", *Endoscopy*, vol. 31, no. 5, pp. 365-369.

- Crowe, P., Harris, P., & Ham, J. 2000, "Teaching on the run: teaching skills for surgical trainees", *Aust.N.Z.J Surg*, vol. 70, no. 3, pp. 227-230.

- Crowell, D. M. 2000, "Building spirited multidisciplinary teams", *J Perianesth.Nurs.*, vol. 15, no. 2, pp. 108-114.

- Cuschieri A 1995, "Visual displays and visual perception in minimal access surgery", *Sem Lap Surg*, vol. 2, pp. 209-214.

- Cuschieri, A. 1995, "Whither minimal access surgery: tribulations and expectations", *Am.J Surg.*, vol. 169, no. 1, pp. 9-19.

- Cuschieri, A. 1996, "Visual display technology for endoscopic surgery", *Min Invs Ther & Allied Technol*, vol. 5, pp. 427-434.

- Czyzewska, E., Kiczka, K., Czarnecki, A., & Pokinko, P. 1983, "The Surgeon's Mental Load During Decision Making at Various Stages of Operations", *Eur J Appl Physiol*, vol. 51, pp. 441-446.

- DAT for selection technical abilities battery manual 1996, *The Psychological Corporation.* Harcourt Brace & Company, London.

- Datta, V., Mackay, S., Mandalia, M., & Darzi, A. 2001, "The use of electromagnetic motion tracking analysis to objectively measure open surgical skill in the laboratory-based model", *J Am.Coll.Surg*, vol. 193, no. 5, pp. 479-485.

- Dawson, D. & Reid, K. 1997, "Fatigue, alcohol and performance impairment", *Nature*, vol. 388, no. 6639, p. 235.

- de Wall, M., van Riel, M. P., Snijders, C. J., & van Wingerden, J. P. 1991, "The effect on sitting posture of a desk with a 10 degree inclination for reading and writing", *Ergonomics*, vol. 34, no. 5, pp. 575-584.

- DeMaria, E. J., McBride, C. L., Broderick, T. J., & Kaplan, B. J. 2005, "Night call does not impair learning of laparoscopic skills", *Surg Innov.*, vol. 12, no. 2, pp. 145-149.

- den Boer, K. T., de Wit, L. T., Davids, P. H., Dankelman, J., & Gouma, D. J. 2001, "Analysis of the quality and efficiency in learning laparoscopic skills", *Surg.Endosc.*, vol. 15, no. 5, pp. 497-503.

- Derossis, A. M., Fried, G. M., Abrahamowicz, M., Sigman, H. H., Barkun, J. S., & Meakins, J. L. 1998, "Development of a model for training and evaluation of laparoscopic skills", *Am.J Surg.*, vol. 175, no. 6, pp. 482-487.

- deVries, H. A., Housh, T. J., Johnson, G. O., Evans, S. A., Tharp, G. D., Housh, D. J., & Hughes, R. A. 1990, "Factors affecting the estimation of physical working capacity at the fatigue threshold", *Ergonomics*, vol. 33, no. 1, pp. 25-33.

- deVries, H. A., Moritani, T., Nagata, A., & Magnussen, K. 1982, "The relation between critical power and neuromuscular fatigue as estimated from electromyographic data", *Ergonomics*, vol. 25, no. 9, pp. 783-791.

- Dion, Y. M. & Gaillard, F. 1997, "Visual integration of data and basic motor skills under laparoscopy. Influence of 2-D and 3-D video-camera systems", *Surg Endosc.*, vol. 11, no. 10, pp. 995-1000.

- Dosis, A., Aggarwal, R., Bello, F., Moorthy, K., Munz, Y., Gillies, D., & Darzi, A. 2005, "Synchronized video and motion analysis for the assessment of procedures in the operating theater", *Arch.Surg*, vol. 140, no. 3, pp. 293-299.

- Dyer, I. R. & Byrne, A. J. 2002, "Heart rate as a measure of stress during real and simulated anaesthetic emergencies", *Anaesthesia*, vol. 57, no. 12, pp. 1215-1216.

- Eastridge, B. J., Hamilton, E. C., O'Keefe, G. E., Rege, R. V., Valentine, R. J., Jones, D. J., Tesfay, S., & Thal, E. R. 2003, "Effect of sleep deprivation on the performance of simulated laparoscopic surgical skill", *Am.J Surg*, vol. 186, no. 2, pp. 169-174.

- Elfving, B., Nemeth, G., Arvidsson, I., & Lamontagne, M. 1999, "Reliability of EMG spectral parameters in repeated measurements of back muscle fatigue", *J Electromyogr.Kinesiol.*, vol. 9, no. 4, pp. 235-243.

- Ellman, P. I., Law, M. G., Tache-Leon, C., Reece, T. B., Maxey, T. S., Peeler, B. B., Kern, J. A., Tribble, C. G., & Kron, I. L. 2004, "Sleep deprivation does not affect operative results in cardiac surgery", *Ann.Thorac.Surg*, vol. 78, no. 3, pp. 906-911.

- Emam, T. A., Frank, T. G., Hanna, G. B., & Cuschieri, A. 2001, "Influence of handle design on the surgeon's upper limb movements, muscle recruitment, and fatigue during endoscopic suturing", *Surg.Endosc.*, vol. 15, no. 7, pp. 667-672.

- Emam, T. A., Hanna, G. B., Kimber, C., & Cuschieri, A. 2000a, "Differences between experts and trainees in the motion pattern of the dominant upper limb during intracorporeal endoscopic knotting", *Dig.Surg.*, vol. 17, no. 2, pp. 120-123.

- Emam, T. A., Hanna, G. B., Kimber, C., Dunkley, P., & Cuschieri, A. 2000b, "Effect of intracorporeal-extracorporeal instrument length ratio on endoscopic task performance and surgeon movements", *Arch.Surg.*, vol. 135, no. 1, pp. 62-65.

- Endsley, M. R. 1995, "Toward a theory of situation awareness in dynamic systems", *Hum.Factors*, vol. 37, no. 1, pp. 32-64.
- Erfanian, K., Luks, F. I., Kurkchubasche, A. G., Wesselhoeft, C. W., Jr., & Tracy, T. F., Jr. 2003, "In-line image projection accelerates task performance in laparoscopic appendectomy", *J.Pediatr.Surg.*, vol. 38, no. 7, pp. 1059-1062.
- Eubanks, T. R., Clements, R. H., Pohl, D., Williams, N., Schaad, D. C., Horgan, S., & Pellegrini, C. 1999, "An objective scoring system for laparoscopic cholecystectomy", *J Am.Coll.Surg*, vol. 189, no. 6, pp. 566-574.
- Firth-Cozens, J. & Moss, F. 1998, "Hours, sleep, teamwork, and stress. Sleep and teamwork matter as much as hours in reducing doctors' stress", *BMJ*, vol. 317, no. 7169, pp. 1335-1336.
- Fogarty, C. & Stern, J. A. 1989, "Eye movements and blinks: their relationship to higher cognitive processes", *Int.J Psychophysiol.*, vol. 8, no. 1, pp. 35-42.
- Fournier, L. R., Wilson, G. F., & Swain, C. R. 1999, "Electrophysiological, behavioral, and subjective indexes of workload when performing multiple tasks: manipulations of task difficulty and training", *Int.J Psychophysiol.*, vol. 31, no. 2, pp. 129-145.
- Francis, N. K., Hanna, G. B., & Cuschieri, A. 2002, "The performance of master surgeons on the Advanced Dundee Endoscopic Psychomotor Tester: contrast validity study", *Arch.Surg*, vol. 137, no. 7, pp. 841-844.

- Gallagher, A. G., Ritter, E. M., Champion, H., Higgins, G., Fried, M. P., Moses, G., Smith, C. D., & Satava, R. M. 2005, "Virtual reality simulation for the operating room: proficiency-based training as a paradigm shift in surgical skills training", *Ann.Surg*, vol. 241, no. 2, pp. 364-372.

- Gawande, A. A., Thomas, E. J., Zinner, M. J., & Brennan, T. A. 1999, "The incidence and nature of surgical adverse events in Colorado and Utah in 1992", *Surgery*, vol. 126, no. 1, pp. 66-75.

- Geryane, M. H., Hanna, G. B., Band, M., Struthers, A. D., & Cuschieri, A. 2004, "Time-motion analysis of operation theatre time use during laparoscopic cholecystectomy by surgical specialist residents", *Surg Endosc.*, vol. 18, pp. 1597-1600.

- Glennerster, A., Rogers, B. J., & Bradshaw, M. F. 1998, "Cues to viewing distance for stereoscopic depth constancy", *Perception*, vol. 27, no. 11, pp. 1357-1365.

- Gold, D. R., Rogacz, S., Bock, N., Tosteson, T. D., Baum, T. M., Speizer, F. E., & Czeisler, C. A. 1992, "Rotating shift work, sleep, and accidents related to sleepiness in hospital nurses", *Am.J Public Health*, vol. 82, no. 7, pp. 1011-1014.

- Goldman, L. I., McDonough, M. T., & Rosemond, G. P. 1972, "Stresses affecting surgical performance and learning. I. Correlation of heart rate, electrocardiogram, and operation simultaneously recorded on videotapes", *J Surg.Res.*, vol. 12, no. 2, pp. 83-86.

- Grantcharov, T. P., Bardram, L., Funch-Jensen, P., & Rosenberg, J. 2001, "Laparoscopic performance after one night on call in a surgical department: prospective study", *BMJ*, vol. 323, no. 7323, pp. 1222-1223.

- Hagberg, M. & Sundelin, G. 1986, "Discomfort and load on the upper trapezius muscle when operating a wordprocessor", *Ergonomics*, vol. 29, no. 12, pp. 1637-1645.

- Hagberg, M. & Wegman, D. H. 1987, "Prevalence rates and odds ratios of shoulder-neck diseases in different occupational groups", *Br.J Ind.Med.*, vol. 44, no. 9, pp. 602-610.

- Hankins, T. C. & Wilson, G. F. 1998, "A comparison of heart rate, eye activity, EEG and subjective measures of pilot mental workload during flight", *Aviat.Space Environ.Med.*, vol. 69, no. 4, pp. 360-367.

- Hanna, G. B., Cresswell, A. B., & Cuschieri, A. 2002, "Shadow depth cues and endoscopic task performance", *Arch.Surg*, vol. 137, no. 10, pp. 1166-1169.

- Hanna, G. B. & Cuschieri, A. 1999, "Influence of the optical axis-to-target view angle on endoscopic task performance", *Surg.Endosc.*, vol. 13, no. 4, pp. 371-375.

- Hanna, G. B. & Cuschieri, A. 2000, "Influence of two-dimensional and three-dimensional imaging on endoscopic bowel suturing", *World J Surg.*, vol. 24, no. 4, pp. 444-448.

- Hanna, G. B., Drew, T., Clinch, P., Hunter, B., & Cuschieri, A. 1998a, "Computer-controlled endoscopic performance assessment system", *Surg Endosc.*, vol. 12, no. 7, pp. 997-1000.

- Hanna, G. B., Drew, T., Clinch, P., Hunter, B., Shimi, S., Dunkley, M. P., & Cuschieri, A. 1996, "A microprocessor-controlled psychomotor tester for minimal access surgery", *Surg.Endosc.*, vol. 10, no. 10, pp. 965-969.

- Hanna, G. B., Frank, T. G., & Cuschieri, A. 1997a, "Objective assessment of endoscopic knot quality", *Am.J.Surg.*, vol. 174, no. 4, pp. 410-413.

- Hanna, G. B., Shimi, S., & Cuschieri, A. 1997b, "Influence of direction of view, target-to-endoscope distance and manipulation angle on endoscopic knot tying", *Br.J.Surg.*, vol. 84, no. 10, pp. 1460-1464.

- Hanna, G. B., Shimi, S., & Cuschieri, A. 1997c, "Optimal port locations for endoscopic intracorporeal knotting", *Surg.Endosc.*, vol. 11, no. 4, pp. 397-401.

- Hanna, G. B., Shimi, S. M., & Cuschieri, A. 1998b, "Randomised study of influence of two-dimensional versus three-dimensional imaging on performance of laparoscopic cholecystectomy", *Lancet*, vol. 351, no. 9098, pp. 248-251.

- Hanna, G. B., Shimi, S. M., & Cuschieri, A. 1998c, "Task performance in endoscopic surgery is influenced by location of the image display", *Ann.Surg.*, vol. 227, no. 4, pp. 481-484.

- Haslegrave, C. M. 1994, "What do we mean by a 'working posture'?", *Ergonomics*, vol. 37, no. 4, pp. 781-799.
- Haynes, D. F., Schwedler, M., Dyslin, D. C., Rice, J. C., & Kerstein, M. D. 1995, "Are postoperative complications related to resident sleep deprivation?", *South.Med.J*, vol. 88, no. 3, pp. 283-289.
- Hockey, G. R. 1997, "Compensatory control in the regulation of human performance under stress and high workload; a cognitive-energetical framework", *Biol.Psychol.*, vol. 45, no. 1-3, pp. 73-93.
- Hodge, B. & Thompson, J. F. 1990, "Noise pollution in the operating theatre", *Lancet*, vol. 335, no. 8694, pp. 891-894.
- Hofmeister J, Frank T G, & Cuschieri A 2001, "Perceptual aspects of two-dimensional and stereoscopic display techniques and endoscopic surgery: Review and current problems", *Sem Lap Surg*, vol. 8, pp. 12-24.
- Holden, J., Frank, T. G., & Cuschieri, A. 1997, "Developing Technology for Suspended Imaging for Minimal Access Surgery", *Semin.Laparosc.Surg.*, vol. 4, no. 2, pp. 74-79.
- Hollmann, S., Klimmer, F., Schmidt, K. H., & Kylian, H. 1999, "Validation of a questionnaire for assessing physical work load", *Scand.J Work Environ.Health*, vol. 25, no. 2, pp. 105-114.
- Hui, L., Ng, G. Y., Yeung, S. S., & Hui-Chan, C. W. 2001, "Evaluation of physiological work demands and low back neuromuscular fatigue on nurses working in geriatric wards", *Appl Ergon.*, vol. 32, no. 5, pp. 479-483.

- Hunting, W., Laubli, T., & Grandjean, E. 1981, "Postural and visual loads at VDT workplaces. I. Constrained postures", *Ergonomics*, vol. 24, no. 12, pp. 917-931.

- Ibbotson, J. A., MacKenzie, C. L., Cao, C. G., & Lomax, A. J. 1999, "Gaze patterns in laparoscopic surgery", *Stud.Health Technol.Inform.*, vol. 62, pp. 154-160.

- Iwanaga, K., Saito, S., Shimomura, Y., Harada, H., & Katsuura, T. 2000, "The effect of mental loads on muscle tension, blood pressure and blink rate", *J Physiol Anthropol.Appl Human Sci.*, vol. 19, no. 3, pp. 135-141.

- Jacobs, R. A. 1999, "Optimal integration of texture and motion cues to depth", *Vision Res.*, vol. 39, no. 21, pp. 3621-3629.

- Jansma, J. M., Ramsey, N. F., Coppola, R., & Kahn, R. S. 2000, "Specific versus nonspecific brain activity in a parametric N-back task", *Neuroimage.*, vol. 12, no. 6, pp. 688-697.

- Jaschinski, W., Heuer, H., & Kylian, H. 1998, "Preferred position of visual displays relative to the eyes: a field study of visual strain and individual differences", *Ergonomics*, vol. 41, no. 7, pp. 1034-1049.

- Jaschinski-Kruza, W. 1988, "Visual strain during VDT work: the effect of viewing distance and dark focus", *Ergonomics*, vol. 31, pp. 1449-1465.

- Jaschinski-Kruza, W. 1991, "Eyestrain in VDT users: viewing distance and the resting position of ocular muscles", *Hum.Factors*, vol. 33, pp. 69-83.

- Jensen, A., Milner, R., Fisher, C., Gaughan, J., Rolandelli, R., & Grewal, H. 2004, "Short-term sleep deficits do not adversely affect acquisition of laparoscopic skills in a laboratory setting", *Surg Endosc.*, vol. 18, no. 6, pp. 948-953.

- Johnston, E. B., Cumming, B. G., & Parker, A. J. 1993, "Integration of depth modules: stereopsis and texture", *Vision Res.*, vol. 33, no. 5-6, pp. 813-826.

- Joice, P., Hanna, G. B., & Cuschieri, A. 1998, "Errors enacted during endoscopic surgery--a human reliability analysis", *Appl Ergon.*, vol. 29, no. 6, pp. 409-414.

- Jones, D. B., Brewer, J. D., & Soper, N. J. 1996, "The influence of three-dimensional video systems on laparoscopic task performance", *Surg Laparosc.Endosc.*, vol. 6, no. 3, pp. 191-197.

- Jorna, P. G. 1992, "Spectral analysis of heart rate and psychological state: a review of its validity as a workload index", *Biol.Psychol.*, vol. 34, no. 2-3, pp. 237-257.

- Jorna, P. G. 1993, "Heart rate and workload variations in actual and simulated flight", *Ergonomics*, vol. 36, no. 9, pp. 1043-1054.

- Keehner, M. M., Tendick, F., Meng, M. V., Anwar, H. P., Hegarty, M., Stoller, M. L., & Duh, Q. Y. 2004, "Spatial ability, experience, and skill in laparoscopic surgery", *Am.J Surg.*, vol. 188, no. 1, pp. 71-75.

- Kleinbeck, S. V. 2000, "Dimensions of perioperative nursing for a national specialty nomenclature", *J Adv.Nurs.*, vol. 31, no. 3, pp. 529-535.

- Kocher, H., Warwick, J., Al Ghnaniem, R., & Patel, A. 2006, "Surgical dexterity after a 'night out on the town'", *ANZ.J Surg*, vol. 76, no. 3, pp. 110-112.

- Kopta, J. A. 1971, "An approach to the evaluation of operative skills", *Surgery*, vol. 70, no. 2, pp. 297-303.

- Kumar, S. & Scaife, W. G. S. 1979, "A precision task, posture and strain", *J Safety Res.*, vol. 11, pp. 28-36.

- Leape, L. L. 1994, "Error in medicine", *JAMA*, vol. 272, no. 23, pp. 1851-1857.

- Leape, L. L., Brennan, T. A., Laird, N., Lawthers, A. G., Localio, A. R., Barnes, B. A., Hebert, L., Newhouse, J. P., Weiler, P. C., & Hiatt, H. 1991, "The nature of adverse events in hospitalized patients. Results of the Harvard Medical Practice Study II", *N.Engl.J Med.*, vol. 324, no. 6, pp. 377-384.

- Lee, C. M., Wood, R. H., & Welsch, M. A. 2001, "Influence of head-down and lateral decubitus neck flexion on heart rate variability", *J Appl.Physiol*, vol. 90, no. 1, pp. 127-132.

- Lee, F. J. & Anderson, J. R. 2001, "Does learning a complex task have to be complex? A study in learning decomposition", *Cognit.Psychol.*, vol. 42, no. 3, pp. 267-316.

- Leijon, O., Wiktorin, C., Harenstam, A., & Karlqvist, L. 2002, "Validity of a self-administered questionnaire for assessing physical work loads in a general population", *J Occup.Environ.Med.*, vol. 44, no. 8, pp. 724-735.

- Liao, M. H. & Drury, C. G. 2000, "Posture, discomfort and performance in a VDT task", *Ergonomics*, vol. 43, no. 3, pp. 345-359.

- Lombard, M. 1995, "Direct Responses to People on the Screen: Television and Personal Space", *Communication Research*, vol. 22, no. 3, pp. 288-324.

- Luttmann, A., Sokeland, J., & Laurig, W. 1996, "Electromyographical study on surgeons in urology. I. Influence of the operating technique on muscular strain", *Ergonomics*, vol. 39, no. 2, pp. 285-297.

- Lyons, J., Elliott, D., Ricker, K. L., Weeks, D. J., & Chua, R. 1999, "Action-Centred Attention in Virtual Environments", *Can J Exp Psychol.*, vol. 53, no. 2, pp. 176-187Can J Exp Psychol.

- Malik, M. 1996, "Heart rate variability. Standards of measurement, physiological interpretation, and clinical use. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology", *Eur.Heart J.*, vol. 17, no. 3, pp. 354-381.

- Martin, M., Vashisht, B., Frezza, E., Ferone, T., Lopez, B., Pahuja, M., & Spence, R. K. 1998, "Competency-based instruction in critical invasive skills improves both resident performance and patient safety", *Surgery*, vol. 124, no. 2, pp. 313-317.

- Matern, U., Faist, M., Kehl, K., Giebmeyer, C., & Buess, G. 2005, "Monitor position in laparoscopic surgery", *Surg.Endosc.*

- Matern, U. & Waller, P. 1999, "Instruments for minimally invasive surgery: principles of ergonomic handles", *Surg.Endosc.*, vol. 13, no. 2, pp. 174-182.

- McNamara, S. A. 1995, "Perioperative nurses' perceptions of caring practices", *AORN J*, vol. 61, no. 2, pp. 377, 380-377, 388.

- Meijman TF 1997, "Mental fatigue and the efficiency of information processing in relation to work times", *International Journal of Industrial Ergonomics*, vol. 20, pp. 31-38.

- Melvin, W. S., Johnson, J. A., & Ellison, E. C. 1996, "Laparoscopic skills enhancement", *Am.J Surg.*, vol. 172, no. 4, pp. 377-379.

- Mishra, R. K., Hanna, G. B., Brown, S. I., & Cuschieri, A. 2004, "Optimum shadow-casting illumination for endoscopic task performance", *Arch.Surg*, vol. 139, no. 8, pp. 889-892.

- Mon-Williams, M. & Dijkerman, H. C. 1999, "The use of vergence information in the programming of prehension", *Exp Brain Res.*, vol. 128, no. 4, pp. 578-582.

- Moorthy, K., Munz, Y., Dosis, A., Bann, S., & Darzi, A. 2003a, "The effect of stress-inducing conditions on the performance of a laparoscopic task", *Surg Endosc.*, vol. 17, no. 9, pp. 1481-1484.

- Moorthy, K., Munz, Y., Sarker, S. K., & Darzi, A. 2003b, "Objective assessment of technical skills in surgery", *BMJ*, vol. 327, no. 7422, pp. 1032-1037.

- Moorthy, K., Munz, Y., Undre, S., & Darzi, A. 2004, "Objective evaluation of the effect of noise on the performance of a complex laparoscopic task", *Surgery*, vol. 136, no. 1, pp. 25-30.

- Moroney, W. F., Biers, D. W., & Eggemeier, F. T. 1995, "Some Measurement and Methodological Considerations in the Application of Subjective Workload Measurement Techniques", *Int.J Aviat.Psychol.*, vol. 5, no. 1, pp. 87-106.

- Mueller, M. D., Camartin, C., Dreher, E., & Hanggi, W. 1999, "Three-dimensional laparoscopy. Gadget or progress? A randomized trial on the efficacy of three-dimensional laparoscopy", *Surg Endosc.*, vol. 13, no. 5, pp. 469-472.

- Neumann, D. L. 2002, "Effect of varying levels of mental workload on startle eyeblink modulation", *Ergonomics*, vol. 45, no. 8, pp. 583-602.

- Nguyen, N. T., Ho, H. S., Smith, W. D., Philipps, C., Lewis, C., De Vera, R. M., & Berguer, R. 2001, "An ergonomic evaluation of surgeons' axial skeletal and upper extremity movements during laparoscopic and open surgery", *Am.J.Surg.*, vol. 182, no. 6, pp. 720-724.

- Nittono, H., Hamada, A., & Hori, T. 2003, "Brain potentials after clicking a mouse: a new psychophysiological approach to human-computer interaction", *Hum.Factors*, vol. 45, no. 4, pp. 591-599.

- Normand, H., Etard, O., & Denise, P. 1997, "Otolithic and tonic neck receptors control of limb blood flow in humans", *J Appl.Physiol*, vol. 82, no. 6, pp. 1734-1738.

- Omar, A. M., Wade, N. J., Brown, S. I., & Cuschieri, A. 2005, "Assessing the benefits of "gaze-down" display location in complex tasks", *Surg Endosc.*, vol. 19, no. 1, pp. 105-108.

- Pan, C. S. & Schleifer, L. M. 1996, "An exploratory study of the relationship between biomechanical factors and right-arm musculoskeletal discomfort and fatigue in a VDT data-entry task", *Appl Ergon.*, vol. 27, no. 3, pp. 195-200.

- Paz-Partlow, M. & Berci, G. 1996, "Practical camera evaluation: A review of principles", *Min Invas Surg & Allied Technol*, vol. 5, pp. 445-449.

- Peters, J. H., Ellison, E. C., Innes, J. T., Liss, J. L., Nichols, K. E., Lomano, J. M., Roby, S. R., Front, M. E., & Carey, L. C. 1991, "Safety and efficacy of laparoscopic cholecystectomy. A prospective analysis of 100 initial patients", *Ann.Surg.*, vol. 213, no. 1, pp. 3-12.

- Pichler, A. V., Radermacher K, & Rau G 1996, "The state of 3-D technology and evaluation", *Min Invas Ther & Allied Technol*, vol. 5, pp. 419-426.

- Pilcher, J. J. & Huffcutt, A. I. 1996, "Effects of sleep deprivation on performance: a meta-analysis", *Sleep*, vol. 19, no. 4, pp. 318-326.

- Pope, D. P., Silman, A. J., Cherry, N. M., Pritchard, C., & Macfarlane, G. J. 1998, "Validity of a self-completed questionnaire measuring the physical demands of work", *Scand.J Work Environ.Health*, vol. 24, no. 5, pp. 376-385.

- Ray, C. A. & Hume, K. M. 1998, "Neck afferents and muscle sympathetic activity in humans: implications for the vestibulosympathetic reflex", *J Appl.Physiol*, vol. 84, no. 2, pp. 450-453.

- Ray, C. A., Hume, K. M., & Shortt, T. L. 1997, "Skin sympathetic outflow during head-down neck flexion in humans", *Am.J Physiol*, vol. 273, no. 3 Pt 2, p. R1142-R1146.

- Reason, J. 2005, "Safety in the operating theatre - Part 2: human error and organisational failure", *Qual.Saf Health Care*, vol. 14, no. 1, pp. 56-60.

- Reznick, R., Regehr, G., MacRae, H., Martin, J., & McCulloch, W. 1997, "Testing technical skill via an innovative "bench station" examination", *Am.J Surg.*, vol. 173, no. 3, pp. 226-230.

- Reznick, R. K. 1993, "Teaching and testing technical skills", *Am.J Surg.*, vol. 165, no. 3, pp. 358-361.

- Richards, C., Rosen, J., Hannaford, B., Pellegrini, C., & Sinanan, M. 2000, "Skills evaluation in minimally invasive surgery using force/torque signatures", *Surg Endosc.*, vol. 14, no. 9, pp. 791-798.

- Richter, P., Wagner, T., Heger, R., & Weise, G. 1998, "Psychophysiological analysis of mental load during driving on rural roads--a quasi-experimental field study", *Ergonomics*, vol. 41, no. 5, pp. 593-609.

- Risucci, D., Geiss, A., Gellman, L., Pinard, B., & Rosser, J. 2001, "Surgeon-specific factors in the acquisition of laparoscopic surgical skills", *Am.J Surg.*, vol. 181, no. 4, pp. 289-293.

- Risucci, D., Geiss, A., Gellman, L., Pinard, B., & Rosser, J. C. 2000, "Experience and visual perception in resident acquisition of laparoscopic skills", *Curr.Surg.*, vol. 57, no. 4, pp. 368-372.

- Rogers, D. A., Regehr, G., Howdieshell, T. R., Yeh, K. A., & Palm, E. 2000, "The impact of external feedback on computer-assisted learning for surgical technical skill training", *Am.J Surg*, vol. 179, no. 4, pp. 341-343.

- Rogers, D. A., Regehr, G., Yeh, K. A., & Howdieshell, T. R. 1998, "Computer-assisted learning versus a lecture and feedback seminar for teaching a basic surgical technical skill", *Am.J Surg*, vol. 175, no. 6, pp. 508-510.

- Rosser, J. C., Jr., Rosser, L. E., & Savalgi, R. S. 1998, "Objective evaluation of a laparoscopic surgical skill program for residents and senior surgeons", *Arch.Surg.*, vol. 133, no. 6, pp. 657-661.

- Rudisill, P. T., Phillips, M., & Payne, C. M. 1994, "Clinical paths for cardiac surgery patients: a multidisciplinary approach to quality improvement outcomes", *J Nurs.Care Qual.*, vol. 8, no. 3, pp. 27-33.

- Saito, S., Miyao, M., Kondo, T., Sakakibara, H., & Toyoshima, H. 1997, "Ergonomic evaluation of working posture of VDT operation using personal computer with flat panel display", *Ind.Health*, vol. 35, no. 2, pp. 264-270.

- Satava, R. M., Cuschieri, A., & Hamdorf, J. 2003, "Metrics for objective Assessment", *Surg Endosc.*, vol. 17, no. 2, pp. 220-226.

- Schneider, W. & Chein, J. M. 2003, "Controlled & automatic processing: behavior, theory, and biological mechanisms", *Cognitive Science*, vol. 27, pp. 525-559.

- Schurr, M. O., Buess, G. F., Kunert, W., Flemming, E., Hermeking H, & Gumb, L. 1996, "Human sense of vision: a guide to future endoscopic emaging systems", *Min Invas Ther Allied Technol*, vol. 5, pp. 410-418.

- Schurr, M. O., Kunert, W., Arezzo, A., & Buess, G. 1999, "The role and future of endoscopic imaging systems", *Endoscopy*, vol. 31, no. 7, pp. 557-562.

- Scott, D. J., Bergen, P. C., Rege, R. V., Laycock, R., Tesfay, S. T., Valentine, R. J., Euhus, D. M., Jeyarajah, D. R., Thompson, W. M., & Jones, D. B. 2000, "Laparoscopic training on bench models: better and more cost effective than operating room experience?", *J Am.Coll.Surg.*, vol. 191, no. 3, pp. 272-283.

- Seghers, J., Jochem, A., & Spaepen, A. 2003, "Posture, muscle activity and muscle fatigue in prolonged VDT work at different screen height settings", *Ergonomics*, vol. 46, no. 7, pp. 714-730.

- Servos, P., Goodale, M. A., & Jakobson, L. S. 1992, "The role of binocular vision in prehension: a kinematic analysis", *Vision Res.*, vol. 32, no. 8, pp. 1513-1521.

- Sexton, J. B., Thomas, E. J., & Helmreich, R. L. 2000, "Error, stress, and teamwork in medicine and aviation: cross sectional surveys", *BMJ*, vol. 320, no. 7237, pp. 745-749.

- Seymour, N. E., Gallagher, A. G., Roman, S. A., O'Brien, M. K., Bansal, V. K., Andersen, D. K., & Satava, R. M. 2002, "Virtual reality training improves operating room performance: results of a randomized, double-blinded study", *Ann.Surg*, vol. 236, no. 4, pp. 458-463.

- Shah, J., Buckley, D., Frisby, J., & Darzi, A. 2003, "Reaction time does not predict surgical skill", *Br.J Surg.*, vol. 90, no. 10, pp. 1285-1286.

- Shapiro, R. A. & Berland, T. 1972, "Noise in the operating room", *N.Engl.J Med.*, vol. 287, no. 24, pp. 1236-1238.

- Sirevaag, E. J., Kramer, A. F., Wickens, C. D., Reisweber, M., Strayer, D. L., & Grenell, J. F. 1993, "Assessment of pilot performance and mental workload in rotary wing aircraft", *Ergonomics*, vol. 36, no. 9, pp. 1121-1140.

- Smith-Coggins, R., Rosekind, M. R., Hurd, S., & Buccino, K. R. 1994, "Relationship of day versus night sleep to physician performance and mood", *Ann.Emerg.Med.*, vol. 24, no. 5, pp. 928-934.

- Sokollik, C., Gross, J., & Buess, G. 2004, "New model for skills assessment and training progress in minimally invasive surgery", *Surg Endosc.*, vol. 18, no. 3, pp. 495-500.

- Soper, N. J., Stockmann, P. T., Dunnegan, D. L., & Ashley, S. W. 1992, "Laparoscopic cholecystectomy. The new 'gold standard'?", *Arch.Surg.*, vol. 127, no. 8, pp. 917-921.

- Steele, R. J., Walder, C., & Herbert, M. 1992, "Psychomotor testing and the ability to perform an anastomosis in junior surgical trainees", *Br.J Surg.*, vol. 79, no. 10, pp. 1065-1067.

- Stern, J. A., Walrath, L. C., & Goldstein, R. 1984, "The endogenous eyeblink", *Psychophysiology*, vol. 21, no. 1, pp. 22-33.

- Straker , L. & Mekhora , K. 2000, "An evaluation of visual display unit by electromyography, posture, discomfort and preference", *International Journal of Industrial Ergonomics*, vol. 26, pp. 389-398.

- Straker, L. M., Pollock, C. M., & Mangharam J.E. 1997, "The effect of shoulder posture on performance, discomfort and muscle fatigue whilst working on a visual display unit", *International Journal of Industrial Ergonomics*, vol. 20, pp. 1-10.

- Taffinder, N., Smith, S. G., Huber, J., Russell, R. C., & Darzi, A. 1999, "The effect of a second-generation 3D endoscope on the laparoscopic precision of novices and experienced surgeons", *Surg.Endosc.*, vol. 13, no. 11, pp. 1087-1092.

- Taffinder, N., Sutton, C., Fishwick, R. J., McManus, I. C., & Darzi, A. 1998a, "Validation of virtual reality to teach and assess psychomotor skills in laparoscopic surgery: results from randomised controlled studies using the MIST VR laparoscopic simulator", *Stud.Health Technol Inform.*, vol. 50, pp. 124-130.

- Taffinder, N. J., McManus, I. C., Gul, Y., Russell, R. C., & Darzi, A. 1998b, "Effect of sleep deprivation on surgeons' dexterity on laparoscopy simulator", *Lancet*, vol. 352, no. 9135, p. 1191.

- Tang, B., Hanna, G. B., & Cuschieri, A. 2005, "Analysis of errors enacted by surgical trainees during skills training courses", *Surgery*, vol. 138, no. 1, pp. 14-20.

- Tang, B., Hanna, G. B., Joice, P., & Cuschieri, A. 2004, "Identification and categorization of technical errors by Observational Clinical Human Reliability Assessment (OCHRA) during laparoscopic cholecystectomy", *Arch.Surg*, vol. 139, no. 11, pp. 1215-1220.

- Tattersall, A. J. & Hockey, G. R. 1995, "Level of operator control and changes in heart rate variability during simulated flight maintenance", *Hum.Factors*, vol. 37, no. 4, pp. 682-698.

- Tendick F & Cavusoglu MC 1997, "Human-Machine Interfaces for Minimally Invasive Surgery", *Proc.1997 Intl.Conf.IEEE Engrg.Med.Biol.Soc., Chicago, IL* pp. 2771-2776.

- Thornton, J. & White, A. 1999, "A Heideggerian investigation into the lived experience of humour by nurses in an intensive care unit", *Intensive Crit Care Nurs.*, vol. 15, no. 5, pp. 266-278.

- Tsubota, K., Miyake, M., Matsumoto, Y., & Shintani, M. 2002, "Visual protective sheet can increase blink rate while playing a hand-held video game", *Am.J Ophthalmol.*, vol. 133, no. 5, pp. 704-705.

- Turville, K. L., Psihogios, J. P., Ulmer, T. R., & Mirka, G. A. 1998, "The effects of video display terminal height on the operator: a comparison of the

15 degree and 40 degree recommendations", *Appl.Ergon.*, vol. 29, no. 4, pp. 239-246.

- Uchal, M., Tjugum, J., Martinsen, E., Qiu, X., & Bergamaschi, R. 2005, "The impact of sleep deprivation on product quality and procedure effectiveness in a laparoscopic physical simulator: a randomized controlled trial", *Am.J Surg*, vol. 189, no. 6, pp. 753-757.

- Uhrich, M. L., Underwood, R. A., Standeven, J. W., Soper, N. J., & Engsberg, J. R. 2002, "Assessment of fatigue, monitor placement, and surgical experience during simulated laparoscopic surgery", *Surg Endosc.*, vol. 16, no. 4, pp. 635-639.

- van Amelsvoort, L. G., Schouten, E. G., Maan, A. C., Swenne, C. A., & Kok, F. J. 2001, "Changes in frequency of premature complexes and heart rate variability related to shift work", *Occup.Environ.Med.*, vol. 58, no. 10, pp. 678-681.

- van Bergen, P., Kunert, W., & Buess, G. F. 2000, "The effect of high-definition imaging on surgical task efficiency in minimally invasive surgery: an experimental comparison between three-dimensional imaging and direct vision through a stereoscopic TEM rectoscope", *Surg.Endosc.*, vol. 14, no. 1, pp. 71-74.

- van der Windt, D. A., Thomas, E., Pope, D. P., de Winter, A. F., Macfarlane, G. J., Bouter, L. M., & Silman, A. J. 2000, "Occupational risk factors for shoulder pain: a systematic review", *Occup.Environ.Med.*, vol. 57, no. 7, pp. 433-442.

- van Veelen, M. A., Kazemier, G., Koopman, J., Goossens, R. H., & Meijer, D. W. 2002, "Assessment of the ergonomically optimal operating surface height for laparoscopic surgery", *J Laparoendosc.Adv.Surg.Tech.A*, vol. 12, no. 1, pp. 47-52.

- van Veelen, M. A., Nederlof, E. A., Goossens, R. H., Schot, C. J., & Jakimowicz, J. J. 2003, "Ergonomic problems encountered by the medical team related to products used for minimally invasive surgery", *Surg.Endosc.*, vol. 17, no. 7, pp. 1077-1081.

- van, V., Meijer, D. W., Goossens, R. H., & Snijders, C. J. 2001, "New ergonomic design criteria for handles of laparoscopic dissection forceps", *J Laparoendosc.Adv.Surg.Tech.A*, vol. 11, no. 1, pp. 17-26.

- Veelen, M. A., Jakimowicz, J. J., Goossens, R. H., Meijer, D. W., & Bussmann, J. B. 2002, "Evaluation of the usability of two types of image display systems, during laparoscopy", *Surg.Endosc.*, vol. 16, no. 4, pp. 674-678.

- Veltman, J. A. & Gaillard, A. W. 1996, "Physiological indices of workload in a simulated flight task", *Biol.Psychol.*, vol. 42, no. 3, pp. 323-342.

- Veltman, J. A. & Gaillard, A. W. 1998, "Physiological workload reactions to increasing levels of task difficulty", *Ergonomics*, vol. 41, no. 5, pp. 656-669.

- Vereczkei, A., Feussner, H., Negele, T., Fritzsche, F., Seitz, T., Bubb, H., & Horvath, O. P. 2004, "Ergonomic assessment of the static stress confronted by surgeons during laparoscopic cholecystectomy", *Surg Endosc.*, vol. 18, no. 7, pp. 1118-1122.

- Vicente, K. J., Thornton, D. C., & Moray, N. 1987, "Spectral analysis of sinus arrhythmia: a measure of mental effort", *Hum.Factors*, vol. 29, no. 2, pp. 171-182.

- Villanueva, M. B., Sotoyama, M., Jonai, H., Takeuchi, Y., & Saito, S. 1996, "Adjustments of posture and viewing parameters of the eye to changes in the screen height of the visual display terminal", *Ergonomics*, vol. 39, no. 7, pp. 933-945.

- Villegas, L., Schneider, B. E., Callery, M. P., & Jones, D. B. 2003, "Laparoscopic skills training", *Surg.Endosc.*, vol. 17, no. 12, pp. 1879-1888.

- Vincent, C., Neale, G., & Woloshynowych, M. 2001, "Adverse events in British hospitals: preliminary retrospective record review", *BMJ*, vol. 322, no. 7285, pp. 517-519.

- Wanzel, K. R., Hamstra, S. J., Caminiti, M. F., Anastakis, D. J., Grober, E. D., & Reznick, R. K. 2003, "Visual-spatial ability correlates with efficiency of hand motion and successful surgical performance", *Surgery*, vol. 134, no. 5, pp. 750-757.

- Welford, A. T. 1978, "Mental work-load as a function of demand, capacity, strategy and skill", *Ergonomics*, vol. 21, no. 3, pp. 151-167.

- Wenzl, R., Lehner, R., Vry, U., Pateisky, N., Sevelda, P., & Husslein, P. 1994, "Three-dimensional video-endoscopy: clinical use in gynaecological laparoscopy", *Lancet*, vol. 344, no. 8937, pp. 1621-1622.

- Wherry, D. C., Rob, C. G., Marohn, M. R., & Rich, N. M. 1994, "An external audit of laparoscopic cholecystectomy performed in medical treatment facilities of the department of Defense", *Ann.Surg.*, vol. 220, no. 5, pp. 626-634.

- Wickens, C. D. 2002, "Situation Awareness and Workload in Aviation", *Current Directions in Psychological Science*, vol. 11, pp. 128-133.

- Wierwille, W. W. & Eggemeier, F. T. 1993, "Recommendations for Mental Workload Measurement in a test and Evaluation Environment", *Hum.Factors*, vol. 35, no. 2, pp. 263-281.

- Wiktorin, C., Hjelm, E. W., Winkel, J., & Koster, M. 1996, "Reproducibility of a questionnaire for assessment of physical load during work and leisure time. Stockholm MUSIC I Study Group. MUSculoskeletal Intervention Center", *J Occup.Environ.Med.*, vol. 38, no. 2, pp. 190-201.

- Wilson, G. F. 1993, "Air-to-ground training missions: a psychophysiological workload analysis", *Ergonomics*, vol. 36, no. 9, pp. 1071-1087.

- Wilson, G. F. 2002, "An Analysis of Mental Workload in Pilots During Flight Using Multiple Psychophysiological Measures", *Int.J Aviat.Psychol.*, vol. 12, no. 1, pp. 3-18.

- Wilson, G. F. & Eggemeier, F. T. 2001, "Mental Workload Measurement," in *International Encyclopedia of Ergonomics and Human Factors*, 1st edn, vol. 1 Waldemar Karwowski, ed., Taylor & Francis, London, pp. 504-506.
- Wolfe, B. M., Szabo, Z., Moran, M. E., Chan, P., & Hunter, J. G. 1993, "Training for minimally invasive surgery. Need for surgical skills", *Surg.Endosc.*, vol. 7, no. 2, pp. 93-95.
- Wright, M. C., Taekman, J. M., & Endsley, M. R. 2004, "Objective measures of situation awareness in a simulated medical environment", *Qual.Saf Health Care*, vol. 13 Suppl 1, p. i65-i71.
- Yamada, F. 1998, "Frontal midline theta rhythm and eyeblinking activity during a VDT task and a video game: useful tools for psychophysiology in ergonomics", *Ergonomics*, vol. 41, no. 5, pp. 678-688.
- Zipp P 1982, "Recommendations for the standardization of lead positions in surface electromyography", *Eur J Appl Physiol*, vol. 50, pp. 41-54.