Applied Ergonomics 43 (2012) 762–767

Contents lists available at SciVerse ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Effect of visual displays and locations on laparoscopic surgical training task

Meghan L. Rogers, Will B. Heath*, Chad C. Uy, Sameerajan Suresh, David B. Kaber

North Carolina State University, Edward P. Fitts Department of Industrial & Systems Engineering, 400 Daniels Hall, 111 Lampe Drive, Raleigh, NC 27695, USA

A R T I C L E I N F O

Article history:
Received 12 May 2011
Accepted 12 November 2011

Keywords:
Minimally invasive surgery
Monitor position

A B S T R A C T

The number of minimally invasive surgical (MIS) procedures has substantially increased since its introduction due to health and recovery benefits for patients. However, there are potential performance issues in MIS for surgeons due to perceptual processing demands associated with supporting technologies. Monitor location has been identified as a major factor influencing performance in these types of procedures. This study examined the effect of multiple monitors on performance during a laparoscopic surgical training task (peg transfer among instruments). Twenty-four novice subjects were exposed to different monitor conditions including a default position, a biomechanically compatible position, and a position collocated with the operating surface as well as the combination of the latter two. Subjective rankings and cognitive workload were also assessed. Results revealed a significant effect of monitor position on task time when compared to subjects' baseline training task time using the default monitor setup. Collocating the monitor with the operating surface was shown to be superior in terms of task time. There were no significant differences among monitor positions in terms of perceived workload. The results of this study provide an applicable guide for the design of MIS setups in the operating room to promote surgeon performance.

1. Introduction

The frequency of minimally invasive surgery (MIS) has increased substantially since its introduction (Cullen et al., 2009). The benefits of this technique include shorter recovery times for the patient and less damage to surrounding tissue. Despite these benefits, MIS poses potential performance issues for surgeons due to perceptual and motor coordination demands associated with existing technologies (DeLucia and Betts, 2008). Using a video display monitor to conduct a procedure can result in decreased viewing quality due to limitations on image resolution as well as a reduced field-of-view, compared with direct visualization. There is a loss of depth perception due to the two-dimensional view provided by laparoscope monitors. In addition, the use of laparoscopic tools decreases the tactile sense of surgery a doctor has compared with traditional surgical tools. Laparoscopic tools also introduce a fulcrum effect in which the movement of the surgeon results in a movement of the working end of the tool in the opposite direction. This effect is not present during direct manipulation as seen in traditional surgeries (Patkin and Isabel, 1995). This fulcrum effect has been shown to slow learning of endoscopic skills during training procedures (Gallagher et al., 1998) by inducing a discrepancy between the actual and expected position of the working ends of the tools.

Compounding these visual and motor feedback issues for doctors in performing these surgeries is the fact that the visual feedback on a procedure is typically separated from the operating field. Studies have shown this separation to be detrimental to performance, increasing error rates in procedures (Wang and MacKenzie, 1999; Matern et al., 2005). Endoscopic surgeons have also been found to experience greater cognitive load due to increased visual scanning for pertinent information across multiple locations, including at the hands and displays (DeLucia and Betts, 2008). The increased visual scanning leads to fatigue, hinders information amalgamation, and delays response times, as well.

Traditional MIS setups require monitors to be placed on an instrument tower (Fig. 1) at a height of 1.65 m (from the floor to the bottom of the monitor) and 1.5 m away from the surgeon (van Veelen et al., 2002a,b). This configuration is largely a product of existing operating room designs/layouts. Unfortunately, such a monitor location would only accommodate the 77th percentile of the U.S. 50/50 mixed population in terms of viewing the surgical display without requiring neck extension (Tayyari and Smith, 1997). To alleviate this issue, MIS suites have begun using adjustable ceiling mounted suspension systems to hold multiple flat screen monitors. Berci et al. (2004) and Herron et al. (2001) found that such a setup provides surgeons with more freedom, in terms of monitor

* Corresponding author. Tel.: +1 919 515 7210.
E-mail address: wbheath@gmail.com (W.B. Heath).

0003-6870/$ – see front matter
doi:10.1016/j.apergo.2011.11.010

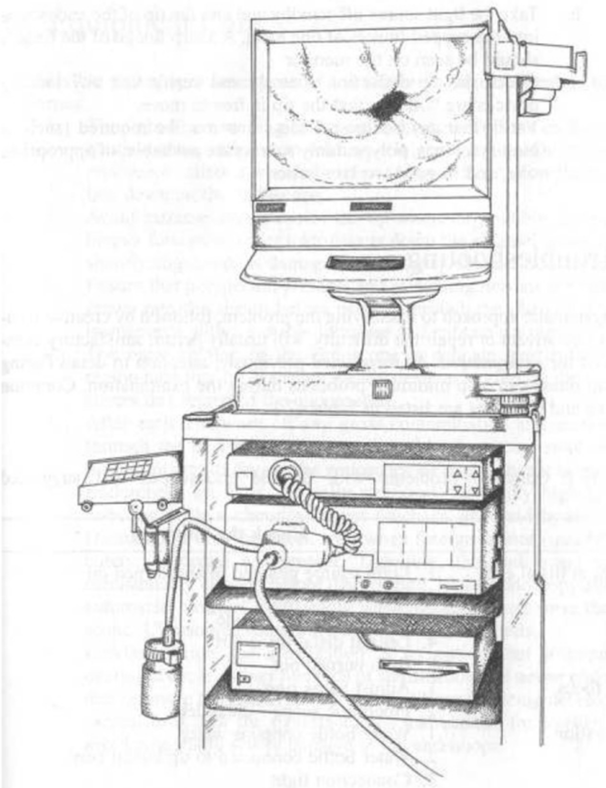

Fig. 1. Current tower setup (Scott-Conner, 2006).

positioning, than did the previous setups using CRT monitor carts (as cited by van Det et al., 2009). This freedom allows surgeons to place the monitor at levels that prevent awkward neck postures.

Monitor location has been shown to be an important factor in the perceptual processing of endoscopic surgery in terms of task performance (Matern et al., 2005; van Veelen et al., 2002b; Hanna et al., 1998; DeLucia and Betts, 2008; Haveran et al., 2007). Unfortunately, previous research has shown a lack of agreement on the best location of monitors during laparoscopic surgery. In a survey conducted by van Veelen et al. (2002b), they found that most participants preferred an ergonomic position of the monitor, which was defined as 15° below eye level at a distance of 0.6 m (see Fig. 2, Position B). In contrast, an earlier study by Hanna et al. (1998) found that a monitor position closer to the surgeons' hands improved task performance. However, in another study by Matern et al. (2005), they showed that there was no statistical difference in task performance between either of the positions. Participants in that study voluntarily identified a preference for having monitors both at the ergonomic position and close to the hands (Matern et al., 2005).

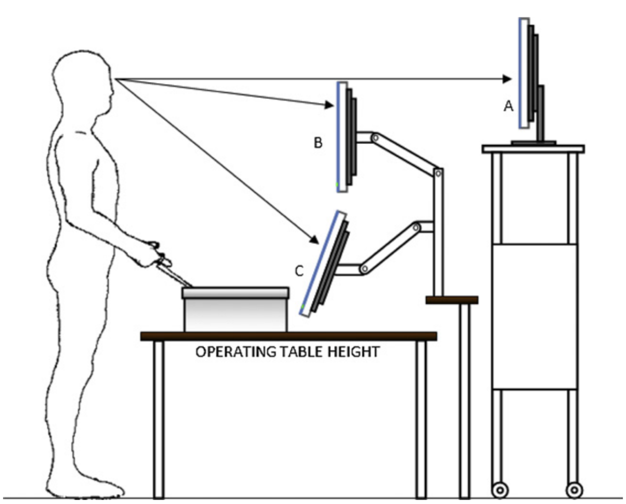

Fig. 2. Monitor configuration.

Matern et al. (2005) also recommended that two monitors be used: one located at eye level to prevent uncomfortable neck postures and one located directly above the patient for more difficult procedures. The suggestion of a dual-monitor setup was surprising for us based on prior research showing the negative effects of visual scanning. Although multiple monitors may allow for greater information presentation, many studies (Liu and Wickens, 1992; Martin-Emerson and Wickens, 1997; Wickens and Carswell, 1995) have demonstrated that visual scanning can lead to delayed response times, increased cognitive workload, and quicker onset of fatigue (as cited by DeLucia and Betts, 2008). Related to this, Shah et al. (2009) tested a dual-monitor condition for laparoscopic suturing with the displays positioned side-by-side. The two monitors presented a zoom image and a panoramic view without zoom. Contrary to their hypothesis, Shah et al. (2009) did not find any significant reductions in error or task times over a single monitor display with optional zoom.

The purpose of this study was to determine which MIS monitor configuration (see Fig. 2) is superior for task performance and moderating workload and whether surgeon preference for multiple displays is supported by objective task measures. Based on the prior research, three monitor conditions were tested including: one monitor positioned 15° below eye level and 0.6 m away from the participant; one monitor collocated with the operating surface; and a dual-monitor configuration including the previous two conditions stacked vertically (see Fig. 2, Positions B and C). The study measured visuo-motor task time and perceived cognitive workload. Subjects were also asked for subjective preferences regarding the three conditions. (We will say more about the dependent measures later.) Based on the findings of Matern et al. (2005), it was hypothesized that subjective ratings would be highest for the dual-monitor condition when compared to the other configurations because of the flexibility in viewing a procedure at different locations. However, based on the negative effects of visual scanning observed in prior human factors studies, it was hypothesized that the dual-monitor configuration would decrease task performance and increase subjective workload when compared to the other single monitor setups. We did not expect the objective task measures to support the previously identified dual-monitor preference due to these negative effects of visual scanning across monitors.

2. Methods

2.1. Participants

Twenty-four subjects (12 males, 12 females) participated in this study. Participants had an average age of 33.2 years (SD = 9.96). To avoid any existing preferences for monitor configurations, subjects were required to be novices with no prior experience in performing any type of surgery. All participants had 20/20 normal or corrected vision and were compensated for their time.

2.2. Experimental task

The task performed during the study was a peg transfer task as part of the Fundamentals of Laparoscopic Surgery (2010) manual skills test. This task has been previously validated for skill transfer to actual laparoscopic procedures. Using laparoscopic graspers (see Fig. 3), the subject lifted small metal objects (nuts) one-by-one from a peg board starting with their non-dominant hand, transferring the object midair to the grasper in their dominant hand, and then placing a nut on a peg on the other side of the board (see Fig. 4). This continued until all metal nuts were moved from the non-dominant side of the board to the dominant side. Then the subjects would repeat the procedure in reverse using the same technique until 24 successful moves were completed. Individual peg transfer times were measured starting when the experimenter gave the command to start and ending when the object was released onto a peg.

2.3. Apparatus

A TaskIt Trainer (Ethicon Endo-Surgery, Inc.; Cincinnati, OH) laparoscopic training device was used for the experiment. The trainer had seven surgical ports and a webcam that connected to a personal computer and delivered task images for projection onto the monitors. The camera was placed at 0° above the peg board based on prior experiment configurations (Zhang and Cao, 2010; Hanna et al., 1997) and provided an orthogonal view of the peg board. The trainer was placed at a height of between 70% and 80% of the subject's elbow height, as suggested by van Veelen et al. (2002a) for an "optimal" ergonomic operating surface height (also see Fig. 3 for typical positioning). Three LCD monitors were used during the experiment. All three monitors (Dell, Round Rock, TX) were 17 inches in diagonal and had a 4:3 aspect ratio. Monitors currently used in actual operating rooms have similar characteristics.

A peg board (Fig. 4) was manufactured to mimic the one used in the Fundamentals of Laparoscopic Surgery (2010) manual skills test based on dimensions provided by the authors. Hex nuts 5/16″ in diameter were used as the object to be transferred. These hex nuts were comparable in size to the objects used in the original test. The peg transfer task was completed using two 5 mm serrated bullnose graspers. The original set of graspers was identical, but during the course of experimentation, one grasper broke beyond repair. Because an identical replacement could not be found, a similar grasper was purchased for use during the remainder of the experiment. The replacement grasper was identical with the exception of its length. The new instrument was approximately 1.8 cm longer than the original. A post-experiment analysis revealed equal variances in performance between the subjects using the original set of graspers and the set of subjects using the replacement grasper.

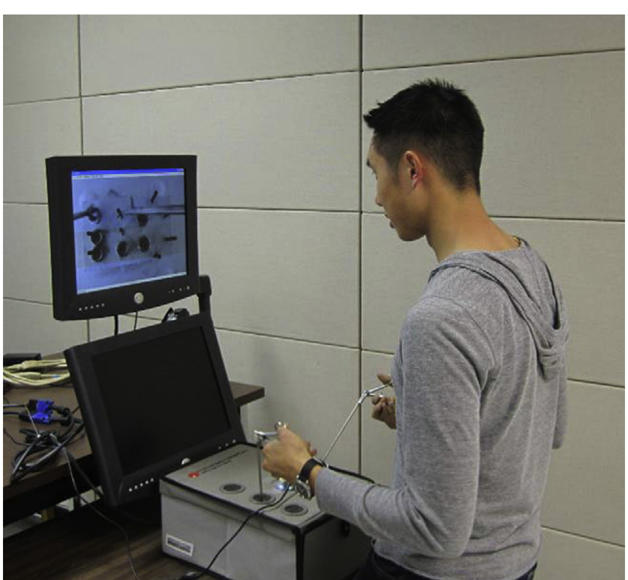

Fig. 3. Experiment setup.

Fig. 4. Peg board.

2.4. Independent variables

Participants were tested under the three different monitor configurations, as described above (and shown in Fig. 2). The presentation of configurations was randomized using a balanced Latin Square design to minimize any response variability due to subject individual differences and carryover learning effects. The angle and distance of the monitor in Position B strictly followed the van Veelen et al. (2002b) setup. For Position C, the monitor was placed at the workstation height at an angle of 20° (Hanna et al., 1998). The third configuration showed the webcam image on the monitors in both Positions B and C, simultaneously (hereafter referred to as Condition "BC").

2.5. Dependent variables

Task performance was measured as the amount of time it took to move one nut from one peg to another. This was considered as the time to complete the fundamental task. Subject workload was assessed using the NASA Task Load indeX (TLX) workload assessment tool. Subjects completed pair-wise comparisons or ranking of workload demand components (mental, physical, effort, temporal, frustration, and performance) after training task performance and before test trials. The participants then provided ratings for demand components after being exposed to each monitor configuration. To account for individual differences in perceived workload scaling, the demand rankings were integrated with the ratings for each monitor configuration in order to determine an overall workload (NASA-TLX) score for each subject.

Subject visual behavior was also recorded during the experiment using a video camera in order to determine which monitor was more frequently used under the dual-monitor condition as well as how often subjects switched between the two. The estimated line of gaze data was used to determine if they scanned across both monitors or focused on one during the dual-monitor trial. A work sampling study approach (statistically reliable sampling) was used to analyze subject estimated line of gaze in post-experiment review of videos. Related to this, subject gaze direction for each monitor position was clearly discriminated in videos by multiple raters.

Finally, a post-experiment subjective survey was used to identify which monitor configuration was preferred by the subjects. Subjects provided rankings of preference among the three monitor conditions with a ranking of 1 being "most preferred" and a ranking of 3 being "least preferred".

2.6. Procedure

Subjects were provided with information on the purpose of the study and provided with a description of the experimental task. They completed an informed consent and provided anthropometric data including height, eye height, and elbow height. Eye height was used to determine the height of monitor Position B and elbow height was used to determine the height of the operating surface. Participants were then provided with a demonstration of how the task was to be performed during the experiment (repeated nut placements). Subsequently, they were given time to familiarize themselves with the tools and handling.

Subject training was divided into two parts. Initially, a clear plastic cover with instrument ports was placed over the TaskIt Trainer so participants could view the task environment directly while still being exposed to the fulcrum effect on the tools (see Fig. 5). The participants were instructed to move all hex nuts to the opposite side of the board and then back again using the transfer technique described above. They were instructed to work as quickly as possible while limiting the number of task errors. During the second part of the training, the TaskIt Trainer top was closed and participants were only able to view the task environment through a monitor located in Position A (see Fig. 2). This configuration mimicked the traditional MIS setup. Marks were placed on the laparoscopic graspers indicating the depth at which they should be inserted into ports to perform the task. Participants performed individual peg transfers at the command of an experimenter. In the event a participant did not follow the correct procedure or a nut was dropped, they were instructed to repeat the trial. The training occurred in sets of 12 peg transfers with each transfer being timed separately. After a set of 12 successful moves, participants were given a 2 min break and their performance was analyzed using regression analysis on a constrained window of their last 24 transfers. Training was terminated once a subject had completed at least 48 moves and the slope coefficient of a power regression model of task time (based on peg count) was within the range of 0 ± 0.1 (i.e., evidence of asymptotic performance). Participants repeated sets of 12 transfers, on average, 5.71 times with a standard deviation of ± 1.04 times. Evidence of sufficient subject training can be seen in the post hoc analyses revealing no significance of the order of conditions (i.e., subjects did not perform significantly better under the 3rd condition as compared to the 1st). Subjects completed the NASA-TLX demand component ranking form before beginning test trials.

Fig. 5. Training setup with open top.

Experiment trials involved 24 iterations of the peg transfer task (successful moves) while using a specific monitor configuration. All trials were videotaped for subject gaze analysis. Under the dual-monitor condition, subjects were instructed to look at the monitor of their choice and that switching during trials was acceptable. After exposure to each test condition, subjects completed the NASA-TLX rating form. Once a subject had been exposed to all monitor conditions, they were given a questionnaire to provide their preference-based rankings of the monitor configurations.

3. Results

3.1. Data processing

Prior to inferential statistical analysis, parametric test assumptions were assessed for the response data sets (Quinn and Keough, 2002). If assumption violations were identified, any necessary variable transformations were applied. To identify any performance advantage of the test monitor configurations over the traditional MIS setup, a derived measure of performance was used. The average task time for each condition was divided by a subjects' training baseline time to obtain a task time ratio ($TT_{ratio} = TT_{average}/TT_{baseline}$, where TT_{ratio} is the task time ratio, $TT_{average}$ is the task time average from experimental trials, and $TT_{baseline}$ is the task time average from the training trails).

A one-way analysis of variance (ANOVA) was used to evaluate the effect of monitor configuration on the task time ratio. The subjective cognitive workload (NASA-TLX) scores were transformed using a Box Cox transformation and the ANOVA was applied. Since the subjective ratings of displays data did not conform with parametric test assumptions, a Kruskal–Wallis test was applied as an alternative to the one-way ANOVA. All analyses were performed with JMP 8.0.1 (Cary, NC). A p-value of 0.05 or less was considered significant. Finally, Tukey's HSD (honestly significant difference) tests were performed as a post hoc analysis to further evaluate any significant effects of monitor configuration.

3.2. Task time ratio

ANOVA results revealed a significant effect of monitor configuration on the task time ratio ($F(2,46) = 3.4814$, $p = 0.0391$). A lower ratio (or smaller fraction of subject baseline time) indicated greater improvement from the traditional MIS setup. Tukey's test revealed Condition C to produce a significantly lower ratio or better task performance (relative to baseline) than Condition B ($\mu = 0.9056 \pm 0.1429$ vs. $\mu = 0.9639 \pm 0.1291$, respectively). The task time ratio for Condition BC also indicated an improvement over baseline performance ($\mu = 0.9346 \pm 0.0895$) and was not significantly different from either condition B or C. Fig. 6 shows the task time ratio differences among the three conditions.

3.3. Cognitive workload

ANOVA results on the transformed cognitive workload scores showed no significant effect of condition ($F(2,46) = 0.6188$,

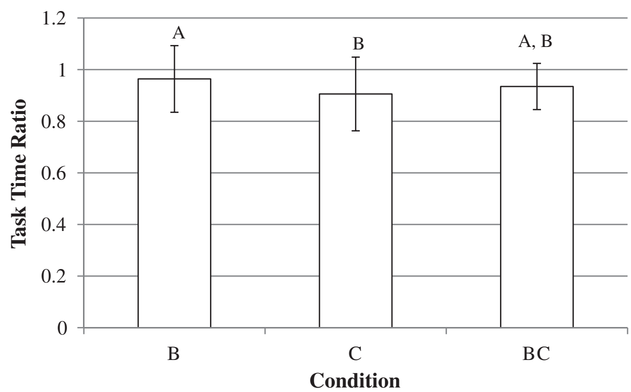

Fig. 6. Task time ratio means per condition. Note: data points in graph with same letter are not significantly different.

$p = 0.5430$). Although not significant, descriptive statistics revealed Condition C to produce a lower average cognitive workload ($\mu = 58.44 \pm 16.28$) as compared with the BC monitor combination ($\mu = 58.97 \pm 13.37$) as well as Condition B ($\mu = 60.76 \pm 14.66$). The score for Condition C ranged from a minimum = 18.3 to a maximum = 82.43 (delta = 64.13). Scores for Condition BC and Condition B ranged from a minimum = 23.1 to a maximum = 88.3 (delta = 65.2) and from a minimum = 25.07 to a maximum = 86.17 (delta = 61.1), respectively.

3.4. Monitor preference

Results of the Kruskal–Wallis test showed no significant effect of monitor configuration on subject preferences ($\chi^2 = 0.4931$, $p = 0.7815$). Although not significant, descriptive statistics revealed Condition B to be most preferred ($\mu = 1.92 \pm 0.80$) compared to Conditions C ($\mu = 2.00 \pm 0.78$) and BC ($\mu = 2.08 \pm 0.90$), based on a rating scale of 1 being most preferred and 3 being least preferred.

3.5. Monitor usage during dual-monitor condition

While performing the peg transfer task under the dual-monitor condition, individual monitor usage was recorded. Results of the Student's *t*-test showed no significant difference between monitor usage ($t = 0.7536$, $p = 0.4549$). Although not significant, descriptive statistics showed Monitor B was used 54% of the time and Monitor C was used the remaining 46% of the time. On average, each subject switched between monitors 2.67 times during a test trial. The maximum number of switches was 13 and the minimum was zero. One-third of the subjects used one monitor exclusively for the entire BC condition; however, the selected monitor varied among subjects. During the dual-monitor condition, B was exclusively used by five subjects and C was exclusively used by three subjects.

4. Discussion

The results of the study showed a substantial decrease in transfer task time for the collocated monitor condition (C) versus the ergonomic monitor position (B) making Position C the superior location in terms of performance. These results are consistent with the findings of Hanna et al. (1998) and Matern et al. (2005). Hanna et al. (1998) found that a monitor position closer to the hands improved task performance (knot tying) and had a higher performance quality score. Similarly, Matern et al. (2005) saw a trend toward better performance in a pearl threading task when participants used the collocated monitor versus a monitor at eye level. Contrary to our hypothesis, the use of dual-monitors was not significantly different from either of the individual monitor configurations. One possible explanation is that during the dual-monitor condition, participants chose to use either Monitor B or Monitor C but rarely switched to use both.

The cognitive workload results revealed no significant differences among the monitor conditions. Analysis of the workload demand components also revealed no difference between conditions. However, descriptive statistics indicated that subjects rated overall Effort and Performance higher than the other four components of the TLX (Mental Demand, Temporal Demand, Frustration, and Physical Demand), across all conditions. This suggested that subjects were concerned with both cognitive and physical aspects of the task and how well they did in peg transfers in assessing workload. The consistency of workload scores can be attributed to the complexity of the task itself from a novice user perspective. Even after numerous test trials, task time remained a substantial fraction of the initial performance time during training, which indicates the difficulty of the task. The complexity of the task potentially overshadowed any variability in cognitive workload due to monitor position. Future studies should consider training subjects to proficiency, as established by the Fundamentals of Laparoscopic Surgery (FLS), or using participants with more experience in laparoscopic procedures to increase resolution and sensitivity in workload analysis.

The average subjective rankings of monitor configuration were also consistent with findings from van Veelen et al. (2002a,b) indicating subjects preferred the laparoscopic task monitor in the ergonomic position (15° below eye level). This observation was opposite to the expectation based on Matern's et al. work that the dual-monitor condition would be preferred. That said, the subject preferences in the present study were still not in line with the performance data. The ergonomic monitor condition (albeit the favorite) yielded slower task times than the collocated monitor position. This contradiction of objective and subjective responses could be attributed to other factors participants may consider when determining preferences, such as physical comfort (i.e., neck flexion) or previous experience in monitor usage. Such disagreement in subject preference and performance has been seen in other studies (Bailey, 1993) and re-enforces the importance of considering a range of response measures, and not just performance, when designing an operating suite. Surgeons may need guidance in terms of the types of technology and configurations that are most effective for addressing perceptual and motor demands of laparoscopic tasks. Tradeoffs need to be considered among surgeon performance and perceived workload. It is possible that higher perceived workload over time may ultimately lead to fatigue and degraded performance. Furthermore, important factors in surgical performance are not limited to speed. Future studies should focus on measuring differences in errors for the various monitor locations and combine all results to optimize the selection of MIS suite setup.

5. Conclusions

Laparoscopic monitor position appears to have a significant effect on MIS task performance (relative to baseline training performance). When the monitor was collocated with the operating surface, task time was quicker than when placed at a position 15° below eye level. However, the dual-monitor condition that was suggested by subjects in the Matern et al. (2005) study revealed no statistical difference from either the collocated monitor or the ergonomically placed monitor.

The scope of this study was limited to human performance and did not take into account the physical ergonomics of the task (e.g., body posture, muscle activity, etc.). In order to address any potential muscle fatigue effects, trials were limited in duration; however, in actual MIS procedures, tasks are typically longer than just 1–3 min. A study that takes into account both the mental and physical aspects of monitor position in laparoscopic surgery might yield more information as to the key factors behind the performance and preference results. Beyond this, the experimental trials were performed within a simulated environment using novice participants with no penalty for errors. This limited any potential motivations or distractions seen during real surgery and might limit the generalizability of results to actual MIS. Novice subjects were used to ensure potential biases did not affect the results, as surgeon performance may actually be adapted to suboptimal monitor configurations. Therefore, novice performance may provide a more sensitive and reliable basis for identifying an optimal monitor configuration. Application of this setup could serve to substantially reduce surgeon effort expended in accommodating a poor monitor configuration. Future research should be conducted to further validate the findings presented here using, for example, experienced surgeons.

One further limitation of this study is related to the objects used during the transfer task. Due to the resources available, metal nuts were used in lieu of specialized transfer objects that might represent human tissue (e.g., soft plastic discs). Although the transfer objects might not be as realistic as the objects typically used in the FLS for training, the task and the objects moved were consistent across all subjects. The difference in the tested material from typical FLS materials, should also not preclude the possibility of improvement in performance through training, based on monitor condition. Furthermore, the higher level of difficulty in moving metal nuts likely increased the sensitivity of the analysis to any differences among conditions.

Acknowledgments

The authors would like to thank Ethicon Endo-Surgery, Inc. for their donation of the TaskIt Trainer and Dr. Simon Hsiang for his input in the initial stages of the project development. This project was supported by the Edward P. Fitts Department of Industrial & Systems Engineering at North Carolina State University.

References

Bailey, R.W., 1993. Performance vs. preference. In: Human Factors and Ergonomics Society Annual Meeting Proceedings, vol. 37. Human Factors and Ergonomics Society. 282–286.

Berci, G., Phillips, E., Fujita, F., 2004. The operating room of the future: what, when and why? Surgical Endoscopy 18 (1), 1–5.

Cullen, K.A., Hall, M.J., Golosinskiy, A., 2009. Ambulatory surgery in the United States, 2006. National Health Statistics Reports 11, 1–25. Retrieved from: http://www.ncbi.nlm.nih.gov/pubmed/21531867.

DeLucia, P.R., Betts, E.T., 2008. Separated versus integrated displays in minimally-invasive surgery. Human Factors and Ergonomics 52 (12), 894.

Fundamentals of Laparoscopic Surgery, 2010. FLS Manual Skills Instructions and Performance Guidelines Retrieved September 15, 2010 from: http://www.flsprogram.org/index/fls-program-description/.

Gallagher, A.G., McClure, N., McGuigan, J., Ritchie, K., Sheehy, N.P., 1998. An ergonomic analysis of the fulcrum effect in the acquisition of endoscopic skills. Endoscopy 30 (7), 617–620. doi:10.1055/s-2007-1001366.

Hanna, G.B., Shimi, S., Cuschieri, A., 1997. Influence of direction of view, target-to-endoscope distance and manipulation angle on endoscopic knot tying. The British Journal of Surgery 84 (10), 1460–1464.

Hanna, G.B., Shimi, S.M., Cuschieri, A., 1998. Task performance in endoscopic surgery is influenced by location of the image display. Annals of Surgery 227 (4), 481–484.

Haveran, L.A., Novitsky, Y.W., Czerniach, D.R., Kaban, G.K., Taylor, M., Gallagher-Dorval, K., et al., 2007. Optimizing laparoscopic task efficiency: the role of camera and monitor positions. Surgical Endoscopy 21 (6), 980–984.

Herron, D.M., Gagner, M., Kenyon, T.L., Swanström, L.L., 2001. The minimally invasive surgical suite enters the 21st century. Surgical Endoscopy 15 (4), 415–422.

Liu, Y., Wickens, C.D., 1992. Visual scanning with or without spatial uncertainty and divided and selective attention. Acta Psychologica 79 (2), 131–153.

Martin-Emerson, R., Wickens, C.D., 1997. Superimposition, symbology, visual attention, and the head-up display. Human Factors: The Journal of the Human Factors and Ergonomics Society 39 (4), 581–601.

Matern, U., Faist, M., Kehl, K., Giebmeyer, C., Buess, G., 2005. Monitor position in laparoscopic surgery. Surgical Endoscopy 19 (3), 436–440.

Patkin, M., Isabel, L., 1995. Ergonomics, engineering and surgery of endosurgical dissection. Journal of the Royal College of Surgeons of Edinburgh 40 (2), 120–132.

Quinn, G.P., Keough, M.J., 2002. Experimental Design and Data Analysis for Biologists. Cambridge University Press, New York, New York, USA.

Scott-Conner, C.E.H., 2006. The SAGES Manual: Fundamentals of Laparoscopy, Thoracoscopy, and GI Endoscopy, second ed. Springer, New York, New York, USA, pp. 533.

Shah, R.D., Cao, A., Golenberg, L., Ellis, R.D., Auner, G.W., Pandya, A.K., et al., 2009. Performance of basic manipulation and intracorporeal suturing tasks in a robotic surgical system: single-versus dual-monitor views. Surgical Endoscopy 23 (4), 727–733.

Tayyari, F., Smith, J.L., 1997. Occupational Ergonomics. Kluwer Academic Publishers, Norwell, MA.

van Det, M.J., Meijerink, W.J.H.J., Hoff, C., Totté, E.R., Pierie, J.P.E.N., 2009. Optimal ergonomics for laparoscopic surgery in minimally invasive surgery suites: a review and guidelines. Surgical Endoscopy 23 (6), 1279–1285.

van Veelen, M.A., Kazemier, G., Koopman, J., Goossens, R.H.M., Meijer, D.W., 2002a. Assessment of the ergonomically optimal operating surface height for laparoscopic surgery. Journal of Laparoendoscopic & Advanced Surgical Techniques 12 (1), 47–52.

van Veelen, M.A., Jakimowicz, J.J., Goossens, R.H.M., Meijer, D.W., Bussmann, J.B.J., 2002b. Evaluation of the usability of two types of image display systems, during laparoscopy. Surgical Endoscopy 16 (4), 674–678.

Wang, Y., MacKenzie, C.L., 1999. Effects of orientation disparity between haptic and graphic displays of objects in virtual environments. Human–Computer Interaction – Interact'99, 391–398.

Wickens, C.D., Carswell, C.M., 1995. The proximity compatibility principle: its psychological foundation and relevance to display design. Human Factors 37 (3), 473.

Zhang, L., Cao, C.G.L., 2010. The effect of image orientation on a dynamic laparoscopic task. In: Proceedings of the Human Factors and Ergonomics Society 54th Annual Meeting, pp. 774–778.