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Project Title: Investigating Visual-Spatial and Psychomotor Skills during Training for Laparoscopic Surgery

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Summary:

Minimally invasive surgery, using laparoscopic techniques, is the standard surgical approach for many operative procedures and its indications continue to expand. Although hands-on training in the operating room is the gold standard for teaching surgical residents these techniques, there has been increased focus on the use of surgical simulators as cost effective and safe alternatives to learning on real patients. On simulators, trainees can practice defined tasks that relate to and build skills that are essential in the modern operating theatre. This project will examine the wrist and hand motions used during laparoscopic manipulation on a previously validated box-trainer task and an interactive, combined manual dexterity-cognitive training, mixed-reality video game platform. The student's objectives will be to refine and run participants through tasks from the Fundamentals of Laparoscopic Surgery (FLS) and the video-gaming environment. They will record and examine the motions made by individuals and determine motion metrics such as position, velocity and acceleration to gauge the quality and skill level of movements performed by individuals.

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Abstract:

The purpose of this study is to examine the hand motions involved in performing laparoscopic surgical tasks and a mixed-reality video game. These motions were recorded through magnetic motion tracking equipment and examined for specific metrics such as position, velocity and acceleration. Through hand motion analysis, we are able develop novel metrics that examine the quality of movements instead of the completion time. The results indicated that participants who were novices to laparoscopic surgery were able to complete test tasks but the accuracy of movements was not high. While both time and accuracy are important, there is still further research that needs to be done to know how useful the assessment of the quality of movement is for evaluating the overall technical skills of surgical residents.

Introduction:

Minimally invasive surgery using laparoscopic techniques, is a modern surgical approach in which procedures are performed with specialized video cameras and long, thin instruments through very small incisions. It has become the standard surgical approach for many operative procedures and its indications continue to expand. Although hands-on training in the operating room is the gold standard for teaching surgical residents these techniques, there has been increased focus on the use of surgical simulators as cost effective and safe alternatives to learning on real patients. On simulators, trainees can practice defined tasks that relate to and build skills that are essential in the modern operating theatre.

There are two main types of laparoscopic simulators: bench-model box trainers and computer-based virtual reality simulators. Practice on both types of simulators has been shown to improve surgical skills in the operating room.[1-2] In addition, several studies have suggested that prior commercial video game experience correlates with laparoscopic skills[3-5] and a single small, randomized study demonstrated that playing video games improves laparoscopic performance[6]. These findings suggest that some of the task components learned in selected video games may be similar to those required for laparoscopy. These may include the development of visual-spatial or working memory cognitive skills as well as improved hand-eye coordination and motor skills.[7] Practice on video games is appealing because they can be fun, are potentially more portable and accessible than simulators, and contain metrics that can act as a source of motivation and feedback. However, a better understanding of how visual-spatial and motor skills are developed during simulation and video game training is necessary to better evaluate technical skills and potentially develop more focused training task sets.

Our specific aim was to investigate the hand motions made during laparoscopic surgery training exercises and how playing a mixed-reality video game, using a laparoscope as an input device, relates to the movements performed during laparoscopic tasks. We examined overall performance based on previously validated scoring systems[8-9] as well as motion metrics known from the literature[10-11].

Materials and Methods:

Ten medical students with no prior laparoscopic experience participated in this study. Each participant performed two repetitions (one repetition with dominant hand and one repetition with the non-dominant hand) of the previously validated peg transfer task from the Society of

American Gastrointestinal and Endoscopic Surgeons (SAGES) approved Fundamentals of Laparoscopic Surgery (FLS) course. Participants performed the task within a laparoscopic box-trainer with laparoscopic graspers. The graspers were instrumented with a magnetic motion tracking system (6 Degrees of Freedom [DOF] Minibird from Ascension Technology Corporation (Burlington, Vermont))that was attached near the tip of the laparoscope and subjects' wrist position was monitored using a SG65 Biometrics electro-goniometer (Biometrics, Gwent, UK) with a sampling frequency of 100Hz. We measured average metrics for position and its 1st and 2nd derivatives (velocity and acceleration) for each segment of data.

The metrics from the Minibird for the peg transfer task were recorded and plotted using Matlab to allow for visualization of the trajectory of motion of the laparoscope. The peg transfer data was collected over the time that each participant took to complete all 12 peg transfers. Each peg transfer was examined as if it were a 4-phase movement curve starting from when the subject grasped the peg. (Figure 1. Segments of 4-phase movement pattern)

The respective phases were averaged and the mean position for each phase was calculated along with the averages of velocity and acceleration. While the peg transfer is normally graded by looking at 2 outcomes, time and number of dropped pegs, the movements themselves are often not graded. The relationship between accurate movements and velocity is an important consideration for assessing surgical skill. During normal movement, when moving towards a target, one will start slow then accelerate to a maximum velocity and then slow down (decelerate) upon reaching the target. When plotting velocity vs. time this yields a normal velocity profile but when plotting velocity vs. position it yields a circular pattern. This serves as a method for analyzing the precision in movement-based tasks but typically, as the velocity of the movement increases, the accuracy naturally decreases.[12]

Each participant then played a video game that had been previously designed for medical rehabilitation to help develop visual-spatial abilities as well as fine-motor control skills.[13] While playing the game, a virtual paddle is slaved to the motion of an instrumented object with a 6-DOF sensor. The goal of the game is to move the paddle left and right by moving the object and to intercept a predetermined target object moving from the top to bottom edge of the display. The starting location of the target object is presented randomly relative to the paddle. The number of game events is configurable depending on session duration, target speed, and number of different motion amplitudes (or events) required.

The index of difficulty can be modified by changing:

- The size of the paddle (i.e. precision level)
- The speed of the targets
- Adding distractors
- Using diagonal trajectories instead of horizontal/vertical ones

The metrics acquired from the game data included success rate, path length, deviation from the ideal path, response time and execution time (the time it takes to complete the movement). The settings used for the game allowed us to obtain a large number of movements of medium length in both directions for analysis.

The instrumented game was the final portion of the testing for the participants. The game was played with 3 different modes to help demonstrate the change in requirements. The instrumented object was a toy car that could roll back and forth with ease and had pegs that could be grasped and held by the laparoscopic instrument. The first mode involved playing the game with a computer mouse and only with the dominant hand. The second mode required the subject to hold onto one of the pegs on the toy car with the laparoscope and then guide it back and forth while interacting with the targets. The third mode required the individual to grasp a peg and then release it with each new target that spawned. The second and third game play modes were both played with dominant and non-dominant hands.

We wanted to create an environment that provided a challenge for the subjects but with enough time for players to react to the changes being presented to them by only using the video feed from the box-trainer. This resulted in the use of a smaller paddle with a longer time for each target to hit the bottom of the screen. Distractors were removed and a horizontal trajectory for movement was used. (Figure 2. Game Screen)

Metrics Measured:

The metrics obtained for the peg transfer included position, velocity, and acceleration, and completion time. As described above, the position data was plotted and cut into segments to allow analysis of individual components of the movement. The position data allows us to examine if there was any overshoot or undershoot by the participant during the actual task since the plateaus would not be level in either of the cases. The velocity was determined by calculating the derivative of the position at each point and then averaged over the time of each movement. The velocity is useful for examining the smoothness of movement through the use of phase profiles. Although it was calculated, the acceleration was not used in our analysis but could be used to create other plots comparing the rate of change in acceleration to the rate of change in position which should typically yield a straight line for a smooth target-based movement.[12] The game data metrics were acquired through use of similar equipment and the values we examined included the success rate, reaction time, execution time, residual error, position, velocity and acceleration. Position, velocity and acceleration served the same purpose as described for the peg transfer.

The success rate on the video game was a measure of the number of targets that were hit with the paddle and is a useful self-motivating measure that participants could see while playing the game and helped to reflect the changes in difficulty between tasks. We expected to see a decrease in the success rate as individuals progressed from using the mouse to the constant hold and then another decrease as we progressed to the grasp-release conditions.

The reaction time on the video game is a measurement of the time between the appearance of the target to initiation of movement. The expectation was to see an increase in the reaction time between conditions as the subject progressed from mouse to constant hold and then to the grasp-release condition. The execution time is the time it takes the subject to complete the movement. This will likely increase over the course of the game conditions (described above). The residual error is a measure of efficiency of movement and we expected to see an increase in this metric with the non-dominant hand grasp-release having the highest value for error.

Results:

The mean completion times (± standard deviation) on the peg transfer task were 137.5 ± 27.8 seconds for the dominant hand and 139.2 ± 41.5 seconds for the non-dominant hand.

In addition to recording completion times, we sought alternate ways to assess technical skill. In particular, we examined the accuracy of movements by applying a phase profile analysis.

As described above, the peg transfer movements were split into 4 different phases. Our main concern involved the ascending and the descending portions of the curves which were the rightward and leftward movements. The upper and lower plateaus are the placement of the peg on the pin (upper) and the picking up of a peg (lower). Through use of phase profile analysis, we examined the different metrics obtained from the peg transfer.

This method illustrates that in a perfectly accurate movement, the phase profile should appear as a circle and that variations in velocity past certain break points lead to overshooting the distance and causing distortions of the circular image and thus, produce less accurate movements.[12] The subject data on the right (Figure 3) helps illustrate the difficulty of maintaining the perfect velocity while performing a task (peg transfer) that requires a higher level of precision.

During the game, the success rate for the mouse was 96.65% ± 0.29. The dominant hand hold had a success rate of 84.05% ± 9.31 and there was a drop in the success rate of the dominant grasp-release to 73.44% ± 9.11. As expected, the non-dominant hand hold and grasp-release trials had lower values for success rate than their dominant hand counter parts. The response times also increased between conditions, with the fastest reaction time occurring with the mouse and the slowest with the non-dominant grasp-release. The execution time was also fastest with the mouse while the non-dominant hand grasp-release had the slowest execution time. The residual error and root mean square (RMS) residual error levels were not significantly different between tasks, although the highest level of error did exist during the non-dominant grasp-release condition. (Table 1, 2 and 3. Game data results.)

We ran correlations between the peg transfer times and the video game metrics when using the dominant hand on both platforms. No significant correlations were found for either completion or execution (rightward movement) times on the peg transfer with success rate, response and execution times on the video game metrics (data not shown).

Discussion:

A phase profile analysis represents a novel way of assessing complex psychomotor movements, but it has not to our knowledge been previously described in the surgical literature. Phase profiling may be useful in assessing surgical aptitude by having individuals perform tasks and comparing their performance to an ideal accepted level or attempting to use an ellipse fit to determine the change from a perfect circle. We are presently examining ways to measure deviation from the perfect circle form in order to quantify the accuracy of movements. This tool would help to indicate not only the time of completion but the accuracy with which the skill was completed. This allows us to find an optimized speed to accuracy ratio. While this may not be as simple as the current standard methods of assessment (completion time and pegs dropped), it could provide additional process measures that further examines the specific movements and provides extra features that could be used to evaluate surgical skill and potentially track the effectiveness of training.

The video game movement metrics demonstrated our expected results including a decrease in the rate of success as each subject progressed from mouse to the constant hold condition and then the grasp-release condition. The decrease in success rate could be due to the increased difficulty of playing the game while using the laparoscope compared to the mouse and also the added difficulty of having to make quick and accurate movements in order to interact with targets.

An interesting outcome was the difference in response time for the different conditions. The change from mouse to the hold conditions was 1.5 times increased and the change from the mouse to the grasp-release conditions was nearly 4 times increased. The execution time more than doubled between the mouse and the dominant hand conditions and nearly tripled from the mouse to the non-dominant hand conditions. These changes in the timing of movements are important to note since they can help reflect the difficulty of initiating movement and thus help indicate the importance of the planning stages and its effects on motion. With practice, the reaction and execution times should improve.

The use of phase profiles can also be used to analyze the game movements. (Figure 5. Phase profiles for game data.) These help illustrate the decrease in precision as individuals progressed from mouse to hold conditions and grasp-release conditions. The phase profiles for the game data only indicate half of a full movement cycle, in this case all of the movements are towards the right. With the mouse profile we can see that it is still a semi-circular shape which would help indicate a precise and controlled movement. This is expected as all subjects have a lot of experience with the mouse and the design makes it very easy to move back and forth. The lack of circular form in the hold indicates a decrease in controlled movement due to inexperience with the laparoscopes or perhaps an increased difficulty in making controlled movements when having to act through the longer arm length. In the grasp-release one can see the complete lack of circular shape. This is likely due to the rapidity of movement which although it may not be directly related to surgical applications, it could still prove to be useful in determining a suitable grasp-release task in which motion metrics more suitable for surgical training could be assessed. As can be seen in comparing the dominant and non-dominant hands, there is less accuracy in the non-dominant hand movement. This is expected as the difficulties in the dominant hand would exist in the non-dominant but would be more pronounced.

We did not demonstrate any significant correlations between peg transfer times and video game metrics. Potential reason for this include: (1) an inadequate sample size and limited variability in skill among participants, which may limit the spread in performances on both the peg transfer task and the video game, (2) limitations in the use of only time as a measure of technical skill on the peg transfer task, (3) limitations in the game metrics, which reflect movement of the sprite (in-game movement) rather than direct hand movements, and (4) that the selected video game represents a different construct from the peg transfer skill. This does not imply that mixed-reality video game platforms do not have potential to augment surgical skill evaluation and training, only that video games and their associated metrics require careful selection and possibly refinement.

Although there may be a place for our motion analysis in the assessment of skill for surgical residents, there is still much work to be done before these forms of analyses could be applied more broadly to improve current methods of testing. The next logical steps would be to examine the data of experienced surgeons and compare the phase profiles to assess the importance of accuracy and controlled motion metrics in the area of surgical training. We also plan on exploring the effect of alternative forms of training on surgical skill through longer and repeated trials of different video games.

Conclusion:

There is a clear importance for new ways of assessing surgical skills and competencies. This project has helped to illustrate a different method of examining laparoscopic skills. Through hand motion analysis of a previously validated peg transfer task, we were able to verify the quality of movements used instead of the completion time. While both have a place, there is still further research that needs to be done to know how useful the assessment of the movement quality is for evaluating the technical skills of surgical residents. We are presently examining ways to measure deviation from the perfect circle form in order to quantify the accuracy of movements. With respect to the video game, more study and better selection is required if such platforms are to be considered for surgical training and evaluation purposes.

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Figures and Tables:

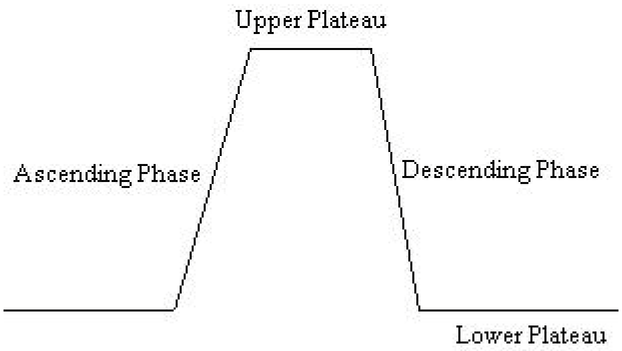

Figure 1.Segments of 4-phases movement pattern. Ascending movements begin after the subject has picked a peg to transfer. The upper plateau represents the fine movements involved in placing the peg on the peg. Descending movements is the return phase to pick up a new peg. Lower plateaus are the fine movements that the individual is using in order to pick up a peg.

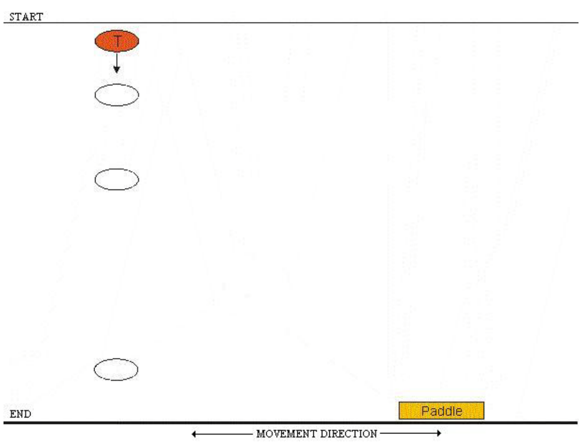

Figure 2.Snapshot of game screen. Circle with label 'T' represents the target with vertical trajectory. Rectangular paddle is able to move left and right along the entire length of the game screen.

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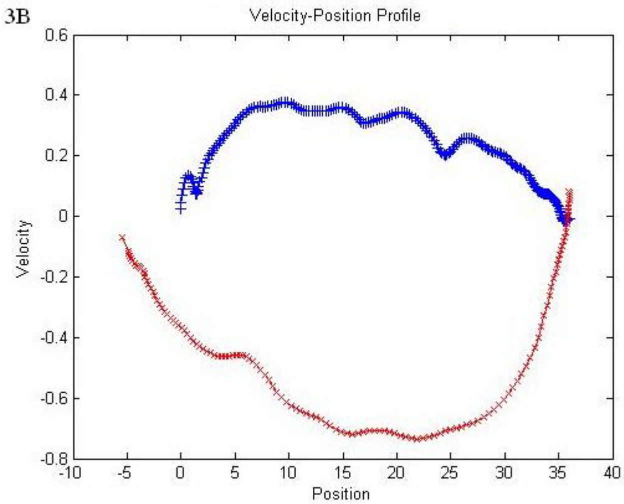

Figure 3. Phase Profile. Velocity-position profile on the peg transfer for representative subject data. This helps demonstrate difficulty in performing the task as well as the lack of precision as velocity is increased.

Condition	% Success
Mean Mouse	96.65 ± 0.29
Mean Dominant Hand Hold	84.05 ± 9.31
Mean Dominant Hand Grasp-Release	73.44 ± 9.11
Mean Non-Dominant Hand Hold	82.46 ± 12.02
Mean Non-Dominant Hand Grasp-Release	65.66 ± 11.90

Table 1.Game Data for success rates.

Condition	Response Time	Execution Time
Mean Mouse	0.49 ± 0.04	0.34 ± 0.16
Mean Dominant Hand Hold	0.71 ± 0.15	0.82 ± 0.28
Mean Dominant Hand Grasp-Release	1.38 ± 0.28	0.86 ± 0.40
Mean Non-Dominant Hand Hold	0.80 ± 0.30	0.96 ± 0.31
Mean Non-Dominant Hand Grasp-Release	1.69 ± 0.78	0.94 ± 0.38

Table 2. Game data for response and execution times

Condition	Residual Error	RMS Residual Error
Mean Mouse	0.20 ± 0.02	0.24 ± 0.02
Mean Dominant Hand Hold	0.19 ± 0.03	0.21 ± 0.04
Mean Dominant Hand Grasp-Release	0.21 ± 0.05	0.24 ± 0.05
Mean Non-Dominant Hand Hold	0.19 ± 0.02	0.21 ± 0.02
Mean Non-Dominant Hand Grasp-Release	0.22 ± 0.05	0.25 ± 0.05

Table 3.Game data for the error in movement.

Figure 4. Game Average Data (X-axis is the duration of movement and the Y-axis is the amplitude of the movement). Top – represents the rightward movements with the mouse. Middle – rightward movements during the dominant hand hold condition. Bottom – rightward movements during the dominant hand grasp-release condition. We see an increase in the reaction time (first red line at the onset of movement) and the execution time (space between red lines for time to complete the movement) and a decrease in precision as we examine from top to bottom.

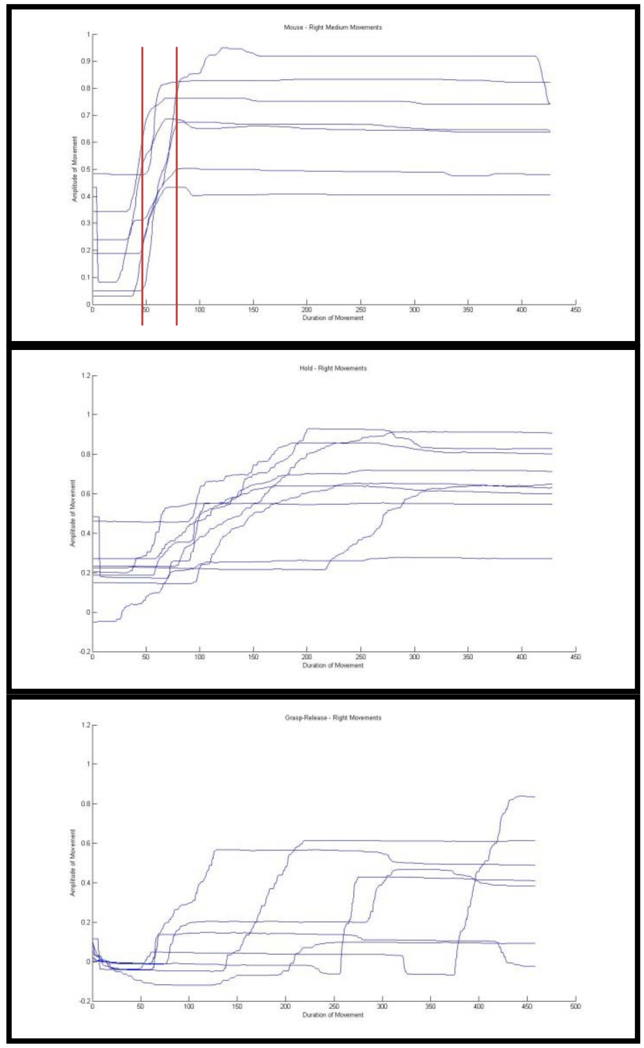

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Figure 5. Phase profiles for game data (X-axis is Position and Y-axis is Velocity). This helps demonstrate the reduction in precision of movements as indicated by the success rates. Top – Phase profile for mouse data, it demonstrates a high level of precision as it is almost a perfect hemi-circle. Middle – Phase profile for hold conditions showing a decrease in precision by using the laparoscopes to control the object. The figure no longer looks circular indicating a less precise and less controlled movement. Bottom – Phase profile for grasp-release conditions. The complete lack of circular form indicates an imprecise movement in which the normal steps of target-based movement are not observed.