COGNITIVE TASK ANALYSIS OF SPATIAL SKILLS IN HYSTERECTOMY WITH THE DA VINCI SURGICAL SYSTEM

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ABSTRACT

Spatial skills have an influence on surgeon’s performance during robot-assisted surgery, and as such should be part of the training. Yet, there is a gap between the current training programs for surgical skills and the needed training of crucial spatial skills.

This work addresses the need to improve skill training in robot-assisted surgery with an innovative approach. The innovative aspects are the analysis and identification of the influential and essential spatial skills in robot-assisted surgery as a basis for training surgeons to improve performance in various conditions.

The overall goal is to identify the crucial spatial skills needed for robot-assisted surgery and introduce them in a training program. The specific objectives are to focus on the cognitive tasks performed during a robot-assisted Hysterectomy and uncover the underlying spatial tasks. In addition, the analysis is aimed at identifying high risk spatial tasks where a failure during the task could increase the risk for both surgeons and patients.

Data collection included observations and interviews, followed by a cognitive task analysis. Spatial tasks and the relevant spatial skills were identified, and high-risk spatial tasks were detected. Finally, the implications of training spatial skills on surgeon’s performance in robot-assisted surgery is discussed.

KEY WORDS


1. Introduction

In the last two decades, the field of robot-assisted surgery has grown and evolved to a point where the technological advances pose challenges and difficulties to the surgeon during the procedure with a robotic surgical system. The demand for cognitive and specifically, spatial skills, is growing along with the rapid advance of the technology. To date, research has primarily focused on the technical and surgical skills during training for robot-assisted surgery. Nevertheless, studies show the importance of various spatial skills such as spatial planning, visualization, the ability to judge spatial relations, and depth perception, in the process of a robot-assisted surgery.

Robot assisted surgery had been investigated both from the technology perspective [8] and the surgical skill perspective [3]. Studies that examined the surgical skills of the surgeon and proficiency levels in various surgical procedures also addresses the issue of evaluation of performance, for example: [2, 12]. The latter studies proposed different sets of matrices, for example: [3] suggested GEARS- Global Evaluation Assessment of Robotic Surgery, which includes six domains: depth perception, binomial dexterity, efficiency, autonomy, force sensitivity and robotic control. Only few of the proposed matrices have a spatial component.

There is a real gap between our understanding of the technological solution for minimally invasive surgery and our ability to evaluate and appreciate the surgeon’s ability to use adequately the innovative technology. Furthermore, out of the available instructional training programs, most emphasize specific surgical procedure such as suturing and knot tying and assess the proficiency level using the same surgical tasks, overlooking the crucial spatial skill assessment during training and evaluation.

Studies use different methods in order to facilitate the necessary skills for robot-assisted surgery. The majority use simulators based on virtual or augmented reality in order to reach the desired level of proficiency (for example, [1]). The latter has shown improved performance as a function of practice in various representative tasks such as the ring tower transfer, peg board and simple suture. Although simulator training was suggested as a valid tool with a good probability of transfer of acquired procedural knowledge to a real setting (for example; [3]), there is no evidence of improvement in the spatial skills that were shown to be critical to the process of a robot-assisted surgery procedure, beyond the surgical- technical skills.

In robot-assisted surgery one of the main concerns should be the possible adverse events due to the lack of surgeon’s proficiency and the fact that the surgeon is operating from
a remote site. In such case, a comprehensive training program should address not only the surgical skill and technical knowledge of the surgical system but also the spatial skill that has proven to be a critical and central component in performing surgery with a robotic surgical system. The criticality of spatial skills and spatial information with regards to robot-assisted surgical procedures is evident both in literature on teleoperation (for example: [10]) and through the present work of Cognitive Task Analysis of hysterectomy procedure.

1.1 Robot Assisted Surgery

During robot-assisted surgery, the surgeon manipulates and controls the robotic arms inside the patient without a direct contact or a direct line of sight. Different technological solutions allow the operator to see and maneuver safely in the absence of physical presence. Yet, along with the state of the art technology, any tele-operation requires the human operator to be skilled at various spatial skills such as mental rotation, visualization, and perspective taking [9, 5]. Thus, it is well established that spatial skills are critical to human operators in robot teleoperations.

1.2 Spatial Skills in Robot-Assisted Surgery

The criticality of visual information and how it is presented to operators is well established in the fields of teleoperation. For example, [1] investigated robot-assisted surgical procedure and concluded that maneuvering the camera to obtain suitable view and depth perception are an important part of the set of skills required during the surgical procedure. Furthermore, studies of robot-assisted surgery training established performance parameters such as “instruments out of view”, “camera targeting”, “depth and visual-spatial perception” and customized tasks for robot-assisted surgery based on proper camera utilization, instrument orientation and depth perception. Although the relation between tele-operation and spatial skills is well established, studies of robot-assisted surgery mainly focus on the technological aspect of the procedure or surgical skill training and assessment. There is a need to address the place of spatial skills in training surgeons for robot-assisted surgery and thus improve quality and safety of the operation.

2. Goals and Objectives

The primary goal is to identify the crucial spatial skills needed for robot-assisted surgery and introduce them in a training program. The objectives are:

- Decompose the surgical procedure into tasks
- Identify and describe the spatial tasks
- Investigate the underlying spatial skills crucial for each spatial task
- Identify high risk spatial tasks
- Discuss implications for training

3. Method

The case for the cognitive task analysis was a robot-assisted hysterectomy. The analysis is based on two observations of a full length robotic assisted hysterectomy as well as simulations of various surgical procedures such as suturing, knot tying and tissue handling. Data was analyzed and represented using the principle of Applied Cognitive Task Analysis method [7]. The steps were as follows: 1. A task diagram was drawn. 2. Audited simulation observation was conducted and 3. Cognitive spatial demands table was created.

4. Findings

4.1 Task Analysis

The basic flow of the surgical procedure is: 1. Console setting and robot preparation, 2. Performing hysterectomy, 3. Suturing and 4. Closing. The observations yielded a series of tasks which are performed during the surgical procedure. The tasks are divided into four basic procedure groups with respect to the basic flow. Two of the groups, which are performed remotely by the surgeon, are presented in Figure 1; hysterectomy and suturing task analysis. Tasks with a spatial component were identified and investigated in Table 1. The relevant spatial skills during the surgical procedures are as follows:

- Spatial Visualization – ability to visualize complicated, multistep manipulations of spatially presented information [6].
- Mental Rotation - the ability to rotate the object mentally in order to conclude how it looks after the rotation (actively, mentally manipulate the object).
- Perspective Taking - the ability to mentally “transfer” oneself to another location in space in order to get a different point of view of the same object.
- Spatial Relation – estimate distance between object in space, directions with regards to one another and depth perception and judgment.
- Spatial Planning – the ability to reason a given spatial situation, visualize and calculate the route and actions to take a few steps ahead. Visualize the steps and their implications throughout the process.

4.2 Identifying High Risk Spatial Task

Invasive surgical procedures, done with MIS (Minimally Invasive Surgery) techniques or otherwise, pose a risk to the patient, such as: injury of the blood vessels, healthy tissue or adjacent organs. Hence, every task that is done inside the patient, using a robotic surgical system, whether is moving, grasping or suturing, involves some degree of risk. Some tasks are mainly a matter of wasted time and
resources such as the decision of the needle insertion point, though undesired delays will affect the surgeons (fatigue and frustration), increase the risk for the patient (such as blood loss) and lead to increased probability of possible complications. Some tasks may cause damage such as extreme movement and touch points between tools or a tool with an unexpected tissue. Such tasks are described as “High risk tasks”; is a task that when performed erroneously will likely result in harm to the patient. Common elements of these tasks are the need for spatial skills in order to avoid risks such as damaging a blood vessel. Each of the mentioned above tasks rely heavily on the surgeon’s ability to visualize the surgical space, plan, reason and project to the future.

The tasks that were identified as “high risk spatial tasks” are characterized as follows: 1. tasks that involve possible injury due to inadequate handling of tools, surrounding blood vessels and tissue. 2. tasks that have a critical spatial element and rely heavily on spatial skills.

Tasks such as needle and thread handling (including insertion, knot tying and transfer), grasping (tissue and needle) and camera adjustment have both a substantial spatial component and are categorized as high risk tasks (see Table 1). Therefore, the probability for a human error while performing these tasks is greater if the surgeon lacks the proper spatial training and skills. For example, during the surgical procedure, the tools should be in the middle of the screen at all times in order to provide the best conditions for assessment and consideration of the next step. To this end, the camera perspective needs to be adjusted perfectly by the surgeon. In order to adjust the camera’s perspective, the surgeon must visualize the possible perspectives and choose the most suited.

The almost invisible step of the decision making based on the spatial information and the skill to gather it, is mostly overlooked and therefore is not considered by most studies to have an effect on the performance. The reality is that only after the decision is made, the surgeon will continue with the perspective changing of the camera. In another scenario, the surgeon may lack the skill of perspective taking and visualization, therefore, a simple strategy of trial and error will be employed. In this case, the implications on the procedure may be of dire consequences such as tissue damaging, tools collision during active suturing that

Figure 1: Robot-assisted Surgery. Upper figure represents the General surgical task analysis. Lower figure represents the suturing Task Analysis. Double rectangle marking tasks with spatial components.
result in needle dropping out of sight. Further, more minor, consequences may be prolonging the operation time, fatigue and frustration and further uncertainty and confusion of the surgeon.

The same principle applies to needle and thread handling and grasping tasks. Grasping a tissue or the needle is a complex spatial task. A slight miscalculation of the distance or depth assessment could potentially cause a needle drop or tissue and vessels damaging.

5. Discussion

Surgical tasks that were identified during the cognitive task analysis of hysterectomy with a significant spatial component are presented in Table 1. Most surgical tasks require the skill of spatial visualization. Spatial visualization, by definition, encompasses both the mental rotation skill and the perspective taking skill. In most tasks, due to insufficient empirical results found in the literature, it is not clear which strategy the surgeon will execute. Generally, it will be visualization, yet, a deeper look into the skills required for a specific task might reveal a more specific spatial skill. For example, if a surgical task is best performed by utilizing the mental rotation skill, the capable surgeon will mentally rotate the object and will reach the needed conclusion regarding it. In the case of inadequacy in performing mental rotation, the surgeon might use perspective taking or a different strategy all together. In that case, the surgical procedure might not go as smoothly as possible, with a slight delay or unnecessary repeated attempts.

The skill of estimating spatial relation between objects in space is also common during a surgical procedure. This skill effects the surgeon’s ability to grasp, place, maneuver and move through the surgical area. Lack of proper training of this skill may results in serious injuries for the patient. Another skill that appear in the analysis is spatial planning. Although the surgeon is capable of performing the surgery and is well familiar with the surgical aspects of the procedure, unexpected events may occur. During an unexpected event, the surgeon might have to deviate from the original plan and proceed with an alternative root. Unlike, in a case of a well-planned, pre-structured procedure, where the trained surgeon works on auto pilot mode. During unexpected events the “auto pilot” is switched off and the surgeon must resolve the situation by using different sets of skills, among others are the spatial skills. For example, the surgeon must work around blood vessels which may have not been mapped, in the moment of the procedure the anatomy mapping and decision making have to be done consciously with all the surgeon’s attention. In each step, the surgeon gather spatial information, project to the future and plan few steps ahead. The mentioned spatial skills of the surgeon are being used each time the surgeon practice robot-assisted surgery. In this way, the surgeon, unknowingly trains these skills.

Three major issues arise: 1. when the surgeon uses a sub-optimal spatial strategy to perform a spatially complex task, odds are that the employed strategy will be adopted if no corrected action is taken 2. The learning process might take a long time because the training isn’t intensive enough and there is no assessment of what was learned. 3. The surgeon might rely on trial and error, this strategy will not improve performance in various surgical procedures. The above three issues lead to the conclusion that a well-structured, spatial skill targeted training program must play a significant and integral part for any comprehensive surgical training program.

6. Conclusions and Implications for Training

The current work sought to reveal the spatial elements in various surgical tasks and gain insight into the cognitive spatial demands during a robot-assisted hysterectomy. Tasks that were identified as having a spatial component were investigated and the relevant spatial skills were identified. The implications of such new knowledge will be critical in the process of creating new training programs for surgeons who practice robot-assisted surgery. Furthermore, the knowledge and categorization of high risk tasks that are spatially complex is critical in order to establish a comprehensive training program with the goal to enhance performance in these key tasks. Improvement in performance in key tasks during a surgical procedure will lead to better outcome both for the surgeon and the patient. In the process of training program construction, the knowledge of the relevant spatial skills to target during training for high risk spatial tasks will enable to construct an efficient and effective training programs for surgeons. The latter will result in better performance during surgical procedure that includes the common procedures such as grasping, suturing and tool handling. Moreover, it will improve performance in different procedures and tasks that rely on the same underlying spatial skills.

A new approach to training and transfer of the identified spatial skills from the training setting to the real setting is a “pure-cognitive, spatial skill targeted” training program that will facilitate the necessary skills out of context and therefore will not be context bound. This approach has two basic assumptions: 1. Targeted training of a specific spatial skill enables the acquisition of the skill with minimal number of confounding variables. 2. Pure cognitive training enables the transfer of the acquired skill from one context to another. Therefore, the execution of the spatial strategy won’t be context bound.

A targeted training program ensures that the specific targeted skills are enhanced and gives insight into the core skills that need the attention and practice. For example, in [4] they used three different cognitive tasks, each focused specifically on the training of the spatial visualization of the student. Furthermore, [11] used a computerized training program which focused on the student’s spatial skills. They concluded that targeted training had improved the spatial skills of undergraduate students as was measured by standardized spatial ability tests. The latter also suggests that a cognitive training program (computer based, without
a motoric skills aspect), is transferrable to a different task, in a different context. In conclusion, this work offers a novel perspective on training for surgeons who practice robot-assisted surgery. It reveals the underlying spatial skills, which through intensive, targeted, pure cognitive training, the tasks that rely on these spatial skills will be performed more efficiently, therefor the implications on the process of the whole surgery will be significant.

Table 1: Performing Hysterectomy and Suturing Tasks

<table>
<thead>
<tr>
<th>Surgical Task</th>
<th>Cognitive Skill</th>
<th>Spatial Skill</th>
<th>Risk to the patient</th>
<th>Task risk analysis (consideration of harm to the patient)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparing the surgical area: Positioning the tools</td>
<td>Visualizing the surgery area</td>
<td>Visualization, spatial planning</td>
<td>Low</td>
<td>In this point there is no robotic tasks involving the movement of the robotic arm inside the patient. Misplacement will prolong the surgery but will not harm the patient.</td>
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<tr>
<td>Path selection</td>
<td>Considering approach strategy, depth and distance estimation, obstacle identification</td>
<td>Visualization, Mental Rotation Perspective Taking, spatial planning, spatial relation</td>
<td>Low</td>
<td>If there are few possible paths for the procedure (begin from left to right or right to left), it will not harm the patient, only effect the convenience of the surgeon.</td>
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<tr>
<td>Locating blood vessels (tissue handling)</td>
<td>Scan, detection and recognition</td>
<td>Visualization, Mental Rotation, Perspective Taking</td>
<td>High</td>
<td>The location of blood vessels is not always obvious. At times the surgeon must uncover and separate tissue in order to reveal and locate the vessels and work around them.</td>
</tr>
<tr>
<td>Mapping anatomy</td>
<td>Scan, detect and identify, categorization</td>
<td>Spatial relation</td>
<td>Low</td>
<td>No arm movement inside the patient.</td>
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<tr>
<td>Grasping point</td>
<td>Scan possible grasping points, identify best suited and project</td>
<td>Visualization, Mental Rotation Perspective Taking, spatial relations, spatial planning</td>
<td>High</td>
<td>The surgeon must assess the spatial relation between objects in a very accurate way. Miscalculation of the target position might result in damaged tissue, tarring a blood vessel or further harm to the patient.</td>
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<tr>
<td>Depth and spatial relation estimation</td>
<td>Visualize, estimate distance, relative depth judgment and surface interpretation</td>
<td>Visualization, Mental Rotation Perspective Taking, spatial relations</td>
<td>High</td>
<td>A basic task. Each subsequent task will rely on an accurate estimation of the surface.</td>
</tr>
</tbody>
</table>
Table 1: Performing Hysterectomy and Suturing Tasks

<table>
<thead>
<tr>
<th>Camera positioning</th>
<th>Detect tools, identify surgical area, calculate and estimate distance, conclude best perspective</th>
<th><strong>Visualization, Mental Rotation Perspective Taking, spatial planning</strong></th>
<th><strong>High</strong></th>
<th>A key task that subsequently effects all tasks. The camera must serve the surgeon so that at all times, the surgeon will be able to change the camera’s perspective for the tools to remain at the center of the screen. Limited view of the tools may result in poor performance and harm the patient in the process.</th>
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<tbody>
<tr>
<td>Tool handling</td>
<td>Estimate distance and relative depth</td>
<td><strong>Spatial relation</strong></td>
<td><strong>High</strong></td>
<td>The surgeon must maneuver the tools inside the patient with extreme caution. For example, miscalculation of the distance to travel may result in tissue damage or further harm to the patient.</td>
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</table>

### Suturing Task

<table>
<thead>
<tr>
<th>Surgical Task</th>
<th>Cognitive Skill</th>
<th>Spatial Skill</th>
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<th><strong>Spatial Skill</strong></th>
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<tr>
<td>Path selection</td>
<td>considering approach strategy, depth and distance estimation, obstacle identification</td>
<td><strong>Visualization, Mental Rotation Perspective Taking, spatial planning, spatial relation</strong></td>
<td><strong>Low</strong></td>
<td>If there are few possible paths for the procedure (begin from left to right or right to left), it will not harm the patient, only effect the convenience of the surgeon.</td>
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<tr>
<td>Tool starting position</td>
<td>Scan surgical area, detect possible positions and plan for path selected</td>
<td><strong>spatial planning</strong></td>
<td><strong>Low</strong></td>
<td>Misplacement will prolong the surgery but will not harm the patient.</td>
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<tr>
<td>Needle grasping</td>
<td>Detect and estimate distance between needle and desired tool</td>
<td><strong>Visualization spatial relations</strong></td>
<td><strong>High</strong></td>
<td>The surgeon must assess the spatial relation between objects in a very accurate way. Miscalculation of the target position might result in damaged tissue, taring a blood vessel, needle dropping out of view or further harm to the patient.</td>
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<td>Task</td>
<td>Description</td>
<td>Visual, Mental, Spatial Variables</td>
<td>Rating</td>
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<tr>
<td>Needle insertion location</td>
<td>Scan for entry points, detect possible points and plan for insertion</td>
<td>spatial planning</td>
<td>High</td>
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<td>Needle insertion</td>
<td>Estimate depth and distance between current needle location and target insertion location</td>
<td>Visualization, Mental Rotation Perspective Taking, spatial relations</td>
<td>High</td>
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<tr>
<td>Needle grasping on exit</td>
<td>Detect needle, estimate distance and relation from current location of the tool to needle</td>
<td>Visualization, Mental Rotation Perspective Taking, spatial relations</td>
<td>High</td>
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<tr>
<td>Needle transfer</td>
<td>Detect second tool, estimate distance and relation from current tool location to target tool location</td>
<td>Visualization, Mental Rotation Perspective Taking, spatial relations, spatial planning</td>
<td>High</td>
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<tr>
<td>Thread handling (such as knot tying)</td>
<td>Estimate distance and relation from current location of the tool to thread</td>
<td>Visualization, Mental Rotation Perspective Taking, spatial relations</td>
<td>High</td>
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<tr>
<td>Camera adjustment</td>
<td>Detect tools, identify surgical area, calculate and estimate distance, conclude best perspective</td>
<td>Visualization, Mental Rotation Perspective Taking, spatial planning</td>
<td>High</td>
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The surgeon must assess the spatial relation between objects in a very accurate way. Miscalculation of the target position might result in damaged tissue, tarring a blood vessel or further harm to the patient.

The surgeon must secure the tie that will hold the tissue together. An unsecure loop will result in tearing tissue, blood loss and further harm to the patient.

The camera must serve the surgeon so that at all times, the surgeon will be able to change the camera’s perspective for the tools to remain at the center of the screen. Limited view of the tools may result in poor performance and harm the patient in the process.
References


