Understanding Cognitive Performance During Robot-Assisted Surgery

Khurshid A. Guru, Somayeh B. Shafiei, Atif Khan, Ahmed A. Hussein, Mohamed Sharif, and Ehsan T. Esfahani

OBJECTIVE To understand cognitive function of an expert surgeon in various surgical scenarios while performing robot-assisted surgery.

MATERIALS AND METHODS In an Internal Review Board approved study, National Aeronautics and Space Administration-Task Load Index (NASA-TLX) questionnaire with surgical field notes were simultaneously completed. A wireless electroencephalography (EEG) headset was used to monitor brain activity during all procedures. Three key portions were evaluated: lysis of adhesions, extended lymph node dissection, and urethro-vesical anastomosis (UVA). Cognitive metrics extracted were distraction, mental workload, and mental state.

RESULTS In evaluating lysis of adhesions, mental state (EEG) was associated with better performance (NASA-TLX). Utilizing more mental resources resulted in better performance as self-reported. Outcomes of lysis were highly dependent on cognitive function and decision-making skills. In evaluating extended lymph node dissection, there was a negative correlation between distraction level (EEG) and mental demand, physical demand and effort (NASA-TLX). Similar to lysis of adhesion, utilizing more mental resources resulted in better performance (NASA-TLX). Lastly, with UVA, workload (EEG) negatively correlated with mental and temporal demand and was associated with better performance (NASA-TLX). The EEG recorded workload as seen here was a combination of both cognitive performance (finding solution) and motor workload (execution). Majority of workload was contributed by motor workload of an expert surgeon. During UVA, muscle memory and motor skills of expert are keys to completing the UVA.

CONCLUSION Cognitive analysis shows that expert surgeons utilized different mental resources based on their need. UROLOGY 86: 751–757, 2015. © 2015 Elsevier Inc.

> *We* are what we repeatedly do. Excellence, then, is not an act, but a habit.
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> —*Aristotle*

The art of surgery is performed in a dynamic environment that constantly challenges human performance. Although technical skills are key tenets of surgical performance, factors such as anatomic knowledge and cognitive expertise are required to define a master surgeon. Concerns regarding transferability of skills from simulation-based training have been questioned due to performance anxiety, true interaction in surgical field, and differences in fidelity and mental load.[1-3]

Poor to virtuoso performance during modern surgery is easily witnessed due to a magnified 3-dimensional view of the surgical field. Surgeons have the opportunity to learn about tool motion with precision and instrument-tissue interaction during robot-assisted surgery, allowing us to evaluate complex dynamics on the operative field.[4,5]

Cognition-based assessment is critical to graduate from novice to master status during the course of training. Mental workload and engagement are the most common metrics used to evaluate the subject's mental states.[6,7] This information is traditionally gathered using self-reported questionnaires and performance-based metrics. Some of these metrics, such as the modified Cooper Harper (MHC) scale,[8] are based on averaged workload scales, whereas others such as The National Aeronautics and Space Administration-Task Load Index (NASA-TLX)[9] comprise subscales that measure specific mental resources, for example, mental effort, physical effort, etc. The major drawback of these measures is that they cannot be unobtrusively administered during the task, but are assessed at the end of the task, which decreases accuracy and reliability of measurement. Moreover, such methods suffer from subjective biases during self-assessment. New

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Financial Disclosure: *The authors declare that they have no relevant financial interests.*
Funding Support: *Support received from Roswell Park Alliance Foundation.*

From the Department of Urology, Applied Technology Laboratory for Advanced Surgery (ATLAS) Program at Roswell Park Cancer Institute, Buffalo, NY; the Department of Mechanical and Aerospace Engineering, Human in the Loop System Laboratory, University at Buffalo, Buffalo, NY; and the Department of Urology, Cairo University, Cairo, Egypt

Address correspondence to: Khurshid A. Guru, M.D., A.T.L.A.S (Applied Technology Laboratory for Advanced Surgery) Program, Elm & Carlton St, Buffalo, NY 14263. E-mail: Khurshid.guru@roswellpark.org

Submitted: March 23, 2015, accepted (with revisions): July 27, 2015

http://dx.doi.org/10.1016/j.urology.2015.07.028
0090-4295/15

advances in brain-computer interfaces have made it possible to monitor individualized cognitive metrics in real time and unobtrusive fashion. The effectiveness of these approaches has already been explored in variety of applications ranging from computer-aided design[10] to human-robot interaction[11,12] and sport training.[13,14] Cognitive assessment of surgeons has been able to clearly distinguish competent and proficient from expert surgeons, despite inability of traditional tool-based metrics.[3,15]

Motor skills are proposed to develop in 3 different stages: the cognitive, associative, and autonomous.[16] Considerable cognitive activity is required at the early stages where the novice is struggling with figuring out the nuances of accomplishing the task. Once the basic skill is acquired, the associative stage begins where he and/or she can direct his attention on the performance rather than the strategy. This cognitive demand will be minimized as the motor skills are mastered and the task can be performed automatically.[16]

Based on surgical expertise an intuitive, fast, automated decision-making process is observed in a master surgeon based on repetitive, pattern recognition, while expending minimal mental energy expenditure. Meanwhile, a novice surgeon attempts deliberate, logical, and automatic steps. As expertise grows, master surgeons anticipate, preempt, and process technical challenges during unexpected operative scenarios. To our knowledge, this is the first study that focuses on understanding cognitive variability during various surgical scenarios encountered by an expert surgeon in terms of cognitive engagement, mental workload, and mental state.

MATERIALS AND METHODS

Study Design

This Internal Review Board approved study (I 241913) started enrollment in September 2013. All robot-assisted surgical procedures were performed by an expert surgeon (KG), with more than 1250 surgical procedures and over 6500 console hours experience. All procedures were de-identified and data were collated. Fifty-one procedures (prostatectomy: 21, cystectomy: 26 and reconstruction: 4) were enrolled in the study. NASA-TLX questionnaire together with field notes of the surgical steps were simultaneously documented.

NASA-Task Load Index Questionnaire

NASA-TLX is one of the most widely utilized subjective validated instruments for assessment of subjective mental workload.[9] The NASA-TLX utilizes a 20-point visual analog score and provides an overall index of mental workload as well as the relative contributions of 6 subscales: mental, physical, temporal task demands, effort, frustration, and perceived performance. The psychometric characteristics of the NASA-TLX have been validated and used by the NASA Ames Research Laboratory for subjective evaluation of individual workload during flight simulation, air traffic control, and vigilance tasks. More recently, our group utilized NASA-TLX assessment of workload perception to separate novice, competent, and proficient and expert surgeons.[15] It should be noted that only for performance assessment in NASA-TLX, *perfect performance* is associated with a *lower* numerical value.

Cognitive Function Assessment

A 20-channel wireless electroencephalogram (EEG) recording device was used to monitor brain activity using an ABM X 24 neuro-headset (Advanced Brain Monitoring, Inc. Carlsberg, CA) during all surgical procedures. Sensors were placed over frontal, central, parietal, and occipital regions. The cognitive output analysis included cognitive metrics (0.1-1.0) for cognitive engagement, mental workload, and mental state for each 1-second epoch. Signal artifacts such as muscle and eye movements were removed, using filtering and classification techniques.[6,7] The expert surgeon participated in a baseline prerecording session where he performed tasks and a 3-choice psychomotor vigilance task to compute cognitive indices. During each task participant's cognitive engagement, mental workload, and mental state were evaluated via wireless EEG recordings.

Surgical Procedures

All surgical procedures performed since September 2013 on the da Vinci Surgical System were enrolled in the study. Three key portions, based on level of complexity and different mental challenges while performing prostatectomy and cystectomy, were included in the analysis: Lysis of adhesions (LOA) (n = 20), extended lymph node dissection (eLND) (n = 21), and urethro-vesical anastomosis (UVA) (n = 19). LOA was included to represent a portion of surgery associated with uncertainty (inability to proceed further, possible associated damage to other key organs or vessels, and level of difficulty). eLND requires careful attention around vessel and thoroughness that meets oncological standards. Meanwhile, UVA rather requires repetitive motor-based skills.

Outcome Measures

The intended outcome measures included both subjective and cognitive assessment of these 3 complex surgical steps.

Subjective Metrics. The subjective metrics recorded were the NASA-TLX questionnaire and the field notes written by the surgeon immediately after completing each individual surgical step. NASA-TLX score is calculated by self-rating on a scale of 1 (low) to 20 (high) for the 6 aforementioned dimensions.

Cognitive Performance Metrics. Three main cognitive metrics extracted from the preprocessed signals were: distraction, mental workload, and mental state. The mental state is related to processes involving information gathering, visual scanning, and sustained attention. It includes high-level, low-level engagement, and cognitive state.[6,7] Distraction measures the level of involvement of cognition of the surgeon while performing the surgical step. Mental workload is correlated with both objective motor performance and loading working memory. Mental state is a discrete index that represents the most probable cognitive state in a given instant (1 second epoch) using numerical values (0.1 = sleep onset, 0.3 = distraction, 0.6 = low engagement, and 0.9 = high engagement). Mental state is represented as combination of high-level engagement and cognitive state.

The surgeon was blinded about the outcomes until the analysis was complete to minimize any cognitive bias. Adequate