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Quantifying the cognitive cost of laparo-endoscopic single-site surgeries: Gaze-based indices

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A B S T R A C T

Background: Despite the growing interest concerning the laparo-endoscopic single-site surgery (LESS) procedure, LESS presents multiple difficulties and challenges that are likely to increase the surgeon's cognitive cost, in terms of both cognitive load and performance. Nevertheless, there is currently no objective index capable of assessing the surgeon cognitive cost while performing LESS. We assessed if gaze-based indices might offer unique and unbiased measures to quantify LESS complexity and its cognitive cost. We expect that the assessment of surgeon's cognitive cost to improve patient safety by measuring fitness-for-duty and reducing surgeons overload.
Methods: Using a wearable eye tracker device, we measured gaze entropy and velocity of surgical trainees and attending surgeons during two surgical procedures (LESS vs. multiport laparoscopy surgery [MPS]). None of the participants had previous experience with LESS. They performed two exercises with different complexity levels (Low: Pattern Cut vs. High: Peg Transfer). We also collected performance and subjective data.
Results: LESS caused higher cognitive demand than MPS, as indicated by increased gaze entropy in both surgical trainees and attending surgeons (exploration pattern became more random). Furthermore, gaze velocity was higher (exploration pattern became more rapid) for the LESS procedure independently of the surgeon's expertise. Perceived task complexity and laparoscopic accuracy confirmed gaze-based results.
Conclusion: Gaze-based indices have great potential as objective and non-intrusive measures to assess surgeons' cognitive cost and fitness-for-duty. Furthermore, gaze-based indices might play a relevant role in defining future guidelines on surgeons' examinations to mark their achievements during the entire training (e.g. analyzing surgical learning curves).

1. Introduction

Laparo-endoscopic single-site surgery (LESS) procedure constitutes one of the most valued minimally-invasive surgery alternatives (Sánchez-Margallo et al., 2014), and it is considered a step forward toward virtually scar-free surgery (Fransen et al., 2012). Since its introduction in 2007, the LESS procedure is undergoing a sustained and rapid exponential growth in the clinical and research fields (Hughes-Hallett et al., 2015; Rao et al., 2011). Compared with conventional multiport laparoscopy surgery (MPS), the benefits of LESS include reduced postoperative pain, earlier return to activities of daily living, and improved cosmesis (Marks et al., 2011). Despite these advantages, the use of LESS has not been widely adopted yet, essentially because of its intrinsic procedural complexity (Botden et al., 2011) and a significantly longer learning curve (Rao et al., 2011; Pafitanis et al., 2015). This increase in complexity might, in fact, lead to a higher procedural failure rate (for a recent meta-analysis comparing single-incision versus conventional

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laparoscopy outcomes in cholecystectomy, see (Trastulli et al., 2013)). Studies suggest that surgeons consider that LESS is not only technically, but cognitively more challenging than conventional laparoscopy (Canes et al., 2008; Islam et al., 2011). As LESS is integrated into the mainstream clinical practice, it is important to understand the key ergonomic differences between LESS and MPS, and the influence of novel instrumentation on surgeons' performance (Sodergren et al., 2013). This is relevant because a highly cognitive cost might yield a greater number of errors and therefore cause a decrement in patient safety when performing LESS procedures. However, LESS training procedures and evaluative methods have not been standardized yet (Zygomalas et al., 2015), and studies measuring the cognitive costs (in terms of both cognitive load and performance) associated to LESS are lacking.

The classical methodology to assess surgical skills, such as subjective measures or technology-based performance measures (Moorthy et al., 2003), only quantifies the cognitive cost related to surgical procedures indirectly. These assessment tools have several advantages as, for instance, they are easy to use and interpret (Tien et al., 2015). But subjective measures introduce biases, whereas technology-based performance measures are expensive to implement. Contrarily, gaze-based indices provide an unobtrusive, objective, direct, and sensitive assessment of the cognitive demands imposed by the surgical procedure, as well as the surgeon ability (Tien et al., 2014). In the last years, considerable progress in technologies have made gaze trackers unobtrusive and inexpensive (Ferhat and Vilariño, 2016; Li and Parkhurst, 2006), making it possible to track surgeons' gaze while they are engaged in surgical tasks (Atkins et al., 2013), to assess medical trainees' learning curves (Alzubaidi et al., 2010), and to differentiate among surgeons of varying surgical skill levels (Law et al., 2004) (for a recent review on the use of gaze tracking in surgery settings, see (Henneman et al., 2017)). Overall, gaze tracking technology, thanks to the high density and richness of the obtainable datasets (Goldstein, 2010), could provide useful information about the safety of healthcare processes (Henneman et al., 2017) and might represent a powerful ergonomic assessment tool. Specifically, recent investigations have shown that gaze-based measures are sensitive enough to detect operator cognitive variations in surgical scenarios (Tien et al., 2015; Di Stasi et al., 2014; Di Stasi et al., 2016). Specifically, entropy-based indices – directly related to gaze behavior – are sensitive to different cognitive demands during real operations (Tien et al., 2015) and can objectively differentiate task complexity during high-fidelity laparoscopic MPS simulations (Di Stasi et al., 2016). Briefly, highly complex/demanding tasks should induce visual strategies aimed at handling the incoming information promptly, causing higher variability (i.e. entropy) of gaze positions (Di Nocera et al., 2007).

Here, to analyze the cognitive costs associated to the LESS procedure, we compared gaze entropy and velocity of healthcare professionals during two surgical procedures while performing two exercises with different complexities. We expected gaze-based measures (i.e. entropy and velocity) to be sensitive to reflect the different cognitive demands imposed by the two surgical procedures (LESS and MPS) and surgical task complexity (Pattern Cut, low complexity and Peg Transfer, high complexity). Furthermore, since visuo-motor skills acquired in conventional MPS do not appear to be directly translatable to the skills required for LESS (Sodergren et al., 2013), and that expert surgeons experienced with LESS are unable to match their overall MPS performance (Santos et al., 2011), it seems plausible to assume that surgeon's level of experience modulates performance during LESS. Thus, we also expected that entropy-based indices would reflect the different cognitive demands for different levels of expertise (surgical trainees vs. attending surgeons).

2. Material and methods

2.1. Ethical approval

We conducted the study in conformity with the Code of Ethics of the World Medical Association (Declaration of Helsinki) (WMA, 1964). The experimental protocol was approved by the University of Granada's Institutional Review Board (IRB approval #899) and written informed consent was obtained from each participant prior to the study.

2.2. Subjects

A total of 16 surgeons (8 surgical trainees and 8 attending surgeons), members of the Andalusian healthcare system and naive to the aim of the experiment, took part in the study. All participants had normal or corrected to normal vision and were right-handed. Surgical trainees (mean ± standard deviation, M ± SD = 26.8 ± 3 years of age; 6 women) attended a laparoscopic training course at the Reina Sofia University Hospital (Cordoba, Spain). All of them were on their first year of the general surgery residency program. Attending surgeons (M ± SD = 33 ± 4 years of age; 5 women) were house staff members at the same hospital, with more than six years of MPS real experience (M ± SD = 6.5 ± 3.3 years, range: 6–15). Both groups had no experience of any kind with LESS procedures, neither simulated nor real. Overall, participants' average shift length was between 9 and 12 h per day (with an average working time of 41–60 h per week). They reported an average 5.5 h of sleep (SD = 1.3) the night before the experimental session. For screening purposes, participants filled in the Stanford Sleepiness Scale (Hoddes et al., 1973) at the beginning of the experimental session. Average SSS score was lower than 3 (M ± SD = 2 ± 0.8), indicating an optimal quality of alertness at the beginning of the study. Average shift length, hours of sleep the night before the experiment, and SSS scores did not differ between the surgical trainees and attending surgeons groups (all p-values > 0.05).

2.3. Experimental design

The study followed a 2 × 2 × 2 mixed factorial design. We considered a) the *surgical experience* (two levels: novice vs. expert) as the between-groups factor, and b) the *surgical procedure* (two levels: LESS vs. MPS), and c) the *surgical task complexity* (two levels: high [Peg Transfer] vs. low [Pattern Cut]) as within-subjects factors. Potential practice/learning effects on the surgical exercises were controlled by a Latin square design across both procedures (half of the participants started with the LESS procedure and the other half with MPS) and across the same procedure (half of the participants performed the Pattern Cut exercise before the Peg Transfer exercise, whereas the second half did the opposite sequence). Thus, the experimental design minimized the possible effects of confounding factors, including learning or series effects, and task-switching costs (i.e. the costs associated with going from a complex task to an easy one). Sample size calculation (using GPower v3.1.9.2) was based on recent published data from our laboratory (Di Stasi et al., 2016) involving the same eye tracker technology, a similar population (i.e., surgical residents [n = 18]) and similar tasks (i.e. laparoscopic exercises). To exceed the general convention of 80% power at the 5% level needed to conclude that a result is significant (Cohen, 1992) for the main analyzed variable – i.e., gaze entropy –, a minimum sample size of $n = 14$ was required.

2.4. Apparatus and tasks

The two surgical procedures and two exercises resulted in four