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A surgeon's brain switch: cortical dynamics of cognitive load in surgeons

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Introduction: A surge in medical robotics has widened the variety and complexity of tools available to surgeons. In a pressurised environment, where split-second decisions are often required, the cognitive demands on surgeons are enormous. Intelligent operating suites comprising cognitively-controlled robotic platforms, may help reduce the surgeons' mental workload and improve technical performance [1-2]. However, such an advanced system requires streamlined switching between traditional and robotic tools, depending on the surgeon's cognitive workload. To study haemodynamic markers of surgeons' workload [3-4], we present results from an authentic surgical environment where surgeons experienced an escalating cognitive demand during a bimanual surgical task. Our findings show the presence of between-subject variability in cortical haemodynamic data and technical performance, suggesting that workload states are dissociable and relate to surgical performance.

Materials & Methods: 28 surgeons performed a laparoscopic suturing exercise in a box trainer (iSurgicals, UK). Subjects created 5 knots under two conditions: 1) self-paced (SP) (max. 300s per knot) 2) time-pressure (TP) (max 120s per knot). A 48-channel functional near-infra-red spectroscopy (fNIRS) system (ETG4000, Hitachi Medical Corp) was used to acquire haemodynamic data from the prefrontal cortex (Fig. 1a). Subjective workload was quantified using the validated Surgical Task Load Index (SURG-TLX) and performance was measured using task progression scores, accuracy scores, leak tests and knot tensile strengths.

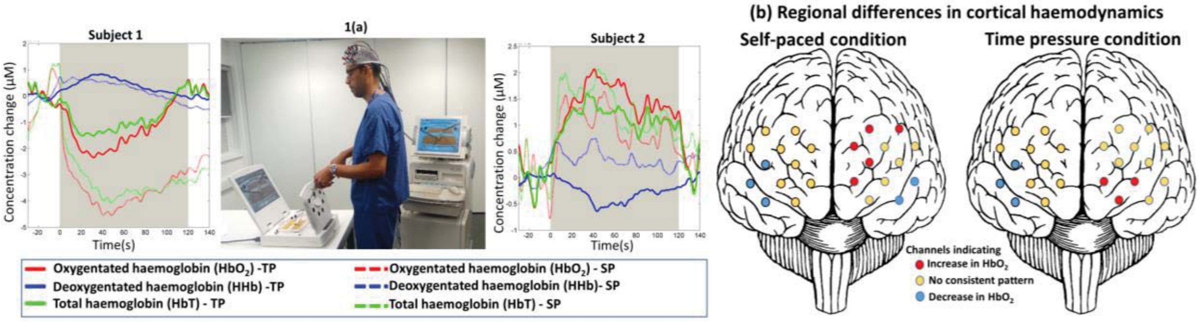

Figure 1. *a) Experimental set-up and mean oxygenation changes for two subjects in self-paced (SP - dotted) and time pressure (TP - solid) conditions. Shaded area depicts task duration with uniformed duration (120s) for both tasks. b) Graphic representation of group trends in channel-wise cortical oxygenation changes exhibiting regional differences in HbO_2 for the two conditions.*

Results: Time courses of mean concentration change in oxygenated haemoglobin (HbO_2) indicate dissociation between the SP and TP conditions. For example, a larger HbO_2 decrease during the SP condition is seen in subject 1, who experienced a greater increase in perceived load under TP and exhibited a larger deterioration in performance (Fig. 1a, Table 1). Conversely, subject 2 showed reverse haemodynamic patterns to subject 1 with a larger HbO_2 increase in TP. Subject 2 experienced less perceived load under TP and exhibited less performance deterioration (Table 1). Condition-wise investigation reveals regional changes in oxygenated haemoglobin. Visual inspection of time courses reveal a general increase in HbO_2 in medial frontal channels in the TP condition, and in ventromedial channels in the SP condition (Fig. 1b).

Table 1: Performance metrics for 2 example subjects

	Self-Paced					Time Pressure				
Subject	**SURG TLX (a.u.)**	**Task Progression Score (a.u.)**	**Accuracy Score (mm)**	**Leak Volume (ml)**	**Tensile Strength (N)**	**SURG TLX (a.u.)**	**Task Progression Score (a.u.)**	**Accuracy Score (mm)**	**Leak Volume (ml)**	**Tensile Strength (N)**
1	59	5.4	2.8	16	47.154	160	2.4	5	25.4	0
2	152	5	1.3	17.6	41.096	196	3.6	3	18.8	20.398

Discussion: The data presented is novel for its subject population, paradigm and the target application. Haemodynamic changes during the two conditions have dissociable trends, indicating the surgeon's cognitive state. Data shows regional variations, indicating the role of inherent cortical structures in processing workload, which may be better revealed by image reconstruction. Further analysis can highlight neural markers of high and low performance, potentially leading to a training intervention for surgical trainees.

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