**SUPPLEMENTARY MATERIAL**

**Keywords and MeSH Terms**

(“functional neuroimaging” OR “neuromonitoring” OR “functional magnetic resonance imaging” OR “fMRI” OR “functional near infrared spectroscopy” OR “NIRS” OR “fNIRS” OR “diffuse optical tomography” OR “diffuse optical imaging” OR “electroencephalography” OR “EEG” OR “positron emission tomography” OR “PET”) AND (“brain function”, “cognitive function”, “neural function”, “brain activation”) AND (“surgery” OR “surgical performance” OR “surgical skill”).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| TABLE 1. Selected studies | | | | | | | | |
| Author | **Imaging modality** | **Paradigm** | **Task** | **Sample size** | **Groups studied** | **Neuroimaging findings** | **Performance** | **Stress** |
| Leff et al (2006)20 | fNIRS | Feasibility study | Open surgical knot tying | 7 | Trainees (n=3), novices (n=4) | Left PFC and left M1 activated in all subjects | T>N |  |
| Leff et al (2007)4 | fNIRS | Technical skills | Open surgical knot tying | 62 | Experts (n=19), trainees (n=21), novices (n=22) | PFC activation: N>T, T=E  PFC activation predominantly L sided in novices | E=T, T>N |  |
| Leff et al (2008)5 | fNIRS | Technical skills | Laparoscopic localisation task | 14 | Novices | Attenuation of PFC activation with skills training |  |  |
| Leff et al (2008)6 | fNIRS | Technical skills | Open surgical knot tying | 19 | Novices | Attenuation of PFC activation with skills training | Performance improved after training |  |
| Leff et al (2008)7 | fNIRS | Technical skills | Open surgical knot tying | 62 | Experts (n=19), trainees (n=21), novices (n=22) | Stable PFC activation in E & T groups over 5 trials  Attenuation of PFC activation in N group over 5 trials | Stable performance in E & T groups over 5 trials  Improved performance in N group over 5 trials |  |
| Ohuchida et al (2009)13 | fNIRS | Technical skills | Laparoscopic knot tying | 21 | Experts (n=4), trainees (n=4), novices (n=13) | PFC activation on initial task performance: N=E, T>E  PFC activation 2 hours training session: N>E | E>T, T>N |  |
| Ros et al (2009)30 | EEG | Neurofeedback | Simulated cataract operation | 20 | Trainee ophthalmologists |  | Improvements in suture score, time on task and overall technique with SMR-T neurofeedback training  No significant improvements in performance with AT neurofeedback training | Reduced STAI scores with SMR-T neurofeedback training  No significant change in STAI scores with AT neurofeedback training |
| Chennat et al (2010)14 | fMRI | Technical skills | Planning & imagined performance of ERCP | 6 | Experts (n=3), novices (n=3) | Motor planning: greater brain activation in experts, especially in the caudate nucleus, limbic region, superior and middle frontal gyri, premotor area, M1 and S1  Imagined performance: no difference in brain activation between novices and experts |  |  |
| James et al (2010)37 | fNIRS | Robot-assisted technology | Visuo-motor tracking task (free hand motor control or GCMC) | 21 | Novices | The GCMC group had more rapid attenuation in PFC activity and more rapid focusing of PPC activity | Better performance observed in the GCMC group |  |
| Bahrami et al (2011)22 | fMRI | Feasibility study | FLS tasks | 2 | Novices | Presence of a box trainer or manipulation of surgical instruments did not produce significant motion artefact or affect the signal to noise ratio |  |  |
| James et al (2011)8 | fNIRS | Technical skills | Navigational task | 29 | Expert endoscopists (n=11), novices (n=18) | Lateral PFC activated in both groups, but greater number of channels activated in the expert group | E>N | No significant fluctuations in HRV or salivary cortisol in either group |
| Zhu et al (2011)45 | EEG | Surgical teaching | Laparoscopic tracking task: implicit vs explicit motor learning | 18 | Novices | Implicit learners show less coactivation of verbal analytic and motor planning areas than explicit learners  No difference between implicit and explicit learners in co-activation of visuospatial and motor planning areas | No difference between implicit and explicit learners in tracking accuracy at retention test |  |
| Duty et al (2012)15 | PET | Technical skills | Laparoscopic peg transfer task & observation of laparoscopic tasks | 10 | Experts (n=5), novices (n=5) | Peg transfer task: *Novices:* activation in L precentral gyrus, L insula, R precuneus gyrus and R inferior occipital gyrus. *Experts:* deactivation in all four of these regions  Task observation: *Novices:* activation in R precuneus gyrus and R cuneus; deactivation in bilateral posterior cerebellum. *Experts:* deactivation in R precuneus gyrus and R cuneus; activation in posterior cerebellum | Overall experts performed better than novices  Novice performance improved from 1st to 2nd peg transfer tasks |  |
| Mylonas et al (2012)36 | fNIRS | Robot-assisted technology | Tracking deforming tissue (free hand motor control or GCMC) | 21 | Novices | Greater PFC activation with GCMC than with free hand control | Better performance observed in the GCMC group |  |
| James et al (2013)35 | fNIRS | Robot-assisted technology | Visuo-motor tracking task (free hand motor control or GCMC) | 21 | Novices | The GCMC group had more rapid attenuation in PFC activity and more rapid focusing of PPC activity  FP networks in the GCMC group were more economic, efficient and small worldly | Better performance observed in the GCMC group |  |
| Bocci et al (2013)33 | EEG | Robot-assisted technology | Laparoscopic & robotic suturing | 16 | Trained surgeons | Increased intra-hemispheric coherence in laparoscopic suturing in theta and lower alpha bands  Increased inter-hemispheric coherence in robotic suturing in upper alpha and beta bands |  |  |
| Bahrami et al (2014)21 | fMRI | Feasibility study | FLS tasks | 9 | Novices | Increasing task complexity resulted in activation of motor and sensory areas, and recruitment of the parietal lobe and medial frontal gyrus | Performance worsened as task complexity increased |  |
| Morris et al (2014)16 | fMRI | Technical skills | Open knot tying & imagining open knot tying | 9 | Experts (n=3), trainees (n=3), novices (n=3) | Activation during knot tying: N>E in M1  Activation during imagining knot tying: E>N in V1, TPJ, posterior STS, L supramarginal area, L rolandic operculum, L postcentral gyrus | Knot quantity:  E>T, T>N  Knot quality:  E=T, T>N |  |
| Guru et al (2015)11 | EEG | Technical skills | Basic, intermediate & advanced robotic tasks | 10 | Experts (n=3), trainees (n=5), novices (n=2) | Cognitive engagement and mental workload in all tasks: N>T, T>E | Technical performance in all tasks: E=T, T>N |  |
| Nemani et al (2015)17 | fNIRS | Technical skills | Laparoscopic pattern cutting in physical box trainer and VR simulator | 9 | Experts (n=2), novices (n=7) | Activation in PFC, M1 & SMA: E<N in box trainer  Activation in PFC & SMA: E>N in VR simulator |  |  |
| Guru et al (2015)12 | EEG | Technical skills | Robotic tasks: LOA, LND, UVA | 1 | Experts (n=1) | Different tasks utilised different cognitive resources |  |  |
| Leff et al (2015)43 | fNIRS | Surgical teaching | Simulated robotic biopsy with and without gaze-assistance from expert | 20 | Novices | Less occipito-parietal activation with gaze-assistance  No difference in global neural efficiency | Gaze-assistance led to superior performance and more efficient visual search strategy | No difference in HR or HRV between gaze-assistance and control conditions |
| Shewokis et al (2015)44 | fNIRS | Surgical teaching | VR laparoscopic cholecystectomy and coordination tasks (blocked vs random practice schedules) | 11 | Medical students | Less activation and greater neural efficiency in PFC with random practice schedule | Better performance in coordination task with random practice schedule |  |
| Miura et al (2015)32 | fNIRS | Robot-assisted technology | VR robotic needle insertion with varying camera angles | 5 | Novices | Peak IPS activation at 75° camera angle |  |  |
| Shetty et al (2016)9 | fNIRS | Technical skills | Laparoscopic knot tying | *Cohort 1: 35*  *Cohort 2:* 13 | *Cohort 1:* Experts (n=11), trainees (n=12) novices (n=12)  *Cohort 2:* Novices | *Cohort 1:* PFC activation: N>E  *Cohort 2:* No attenuation in PFC activity in novices after 8 hours training | *Cohort 1:* E>T>N  *Cohort 2:* N (post-training)=E |  |
| Andreu-Perez et al (2016)10 | fNIRS | Technical skills | Laparoscopic knot tying | 32 | Experts (n=9), trainees (n=11), novices (n=12) | Stronger prefrontal and premotor connectivity among novices | E>T>N | No significant differences in HR or HRV between groups |
| Leff et al (2016)42 | fNIRS | Intraoperative decision-making | Observation of simulated laparoscopic cholecystectomy with (primed) and without (unprimed) operative cues | 22 | Experts (n=5), trainees (n=7), novices (n=10) | N: significant activation in dorsolateral, ventrolateral and medial PFC in unprimed scenarios; no significant activation in primed scenarios  T & E: no significant activation in either unprimed or primed scenarios |  | No significant difference in STAI scores between groups |
| PFC: prefrontal cortex; PPC: posterior parietal cortex; SPL: superior parietal lobe; TPJ: temporo-parietal junction; STS: superior temporal sulcus; M1: primary motor cortex; SMA: supplementary motor area; V1: primary visual cortex; IPS: intraparietal sulcus; RHD: right hand dominant; PGY: post graduate year; GCMC: gaze-contingent motor control; E: experts; T: trainees; N: novices; HR: heart rate; HRV: heart rate variability; R: right; L: left; ERCP: endoscopic retrograde cholangiopancreatography; MRT: mental rotation task; SMR-T: sensorimotor rhythm-Theta; AT: alpha/theta; STAI: State Trait Anxiety Inventory; FLS: Fundamentals of Laparoscopic Surgery; FP: fronto-parietal; VR: virtual reality; LOA: lysis of adhesions; LND: lymph node dissection; UVA: urethrovesical anastomosis | | | | | | | | |