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Brain network regional flexibility has relationship with mental workload during robot-assisted surgery performance

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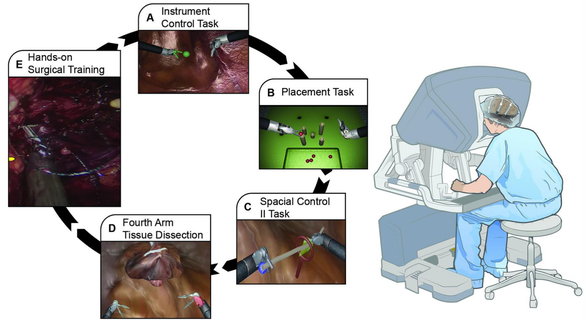
Introduction

- Commonly, Mental Workload (MWL) refers to the proportion of an individual's total mental capacity used at that certain moment.
- The individual's brain ability to process information spontaneously is limited, and overload information can lead to poor performance.
- MWL of surgeons during Robot-assisted surgery (RAS) has been frequently evaluated using subjective methods.
- However, currently there is no methodology proposed for objective assessment of RAS surgeon's MWL.
- RAS is much more complicated than regular activities due to:
  - It involves human-robot interaction.
  - Quick demands and appropriate reactions to uneven circumstances.
  - Multitasking characteristic as it demands frequent switches between surgical subtasks.
- In this study we used Electroencephalogram (EEG) features to retrieve information about MWL while performing surgical tasks on a robot simulator.

Method

Subjects and Sessions: Electroencephalogram (EEG) data from **22** medical students was recorded during **six** sessions over **one year** of practice, performing five RAS tasks on Robotic Surgery Simulator - fundamental skills of robotic surgery (FSRS):



Set up and schematic of RAS tasks to acquire skills related to human-machine interface. A 20-channel EEG headset was used to record trainee's brain activity while performing tasks.

Task	Instrument control	Ball placement	Spatial control II	Fourth arm tissue dissection	Hands-on surgical training
Complexity level	2	4	5	3	1

Level of Task Complexity (1: lowest complexity, 5: highest complexity):

Data & Analysis

Data: EEG data was recorded using a 20-channel EEG headset.

EEG data recording was carried out at the **initial session** and were followed at **one week**, **one month**, **three months**, **six months**, and **one year** intervals.

EEG data was recorded by placing the channels sensors of a 20-channel EEG headset on the:

- **Frontal** (F; cognition and action area; F3, Fz, F4, F7, F8 electrode channels)
- **Prefrontal** (PF; cognition area; Fp1, Fp2 electrode channels)
- **Central** (C; action area; C3, Cz, C4 electrode channels)
- **Temporal** (T; perception area; T3, T4, T5, T6 electrode channels)
- **Parietal** (Pa; cognition area; P3, Pz, P4, Poz electrode channels)
- **Occipital** (O; perception area; O1, O2 electrode channels) cortices.

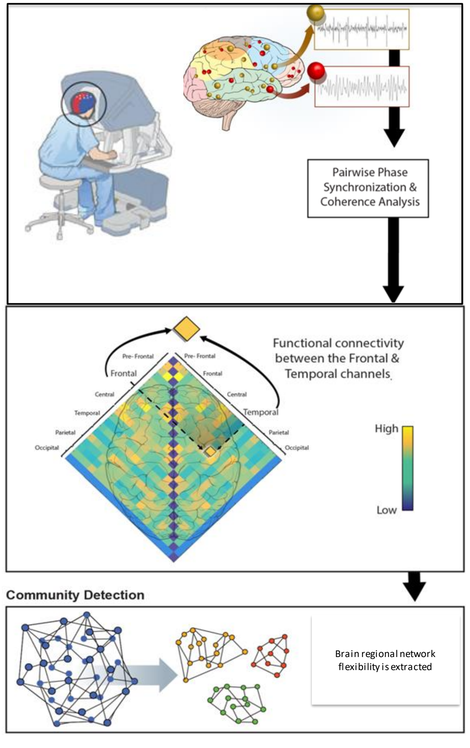
Total EEG recordings used in this study are **420**.

- Every stimulus activates different neurons throughout the brain.
- The interaction of these different brain areas decreases human cognitive load, and consequently leads to smooth performance.
- We considered this concept, and implemented brain network analyses to extract features that quantify the changes of the human cognitive load.

Network flexibility Feature: Portion of time that brain area changes its functional community status as a response towards processing a task.

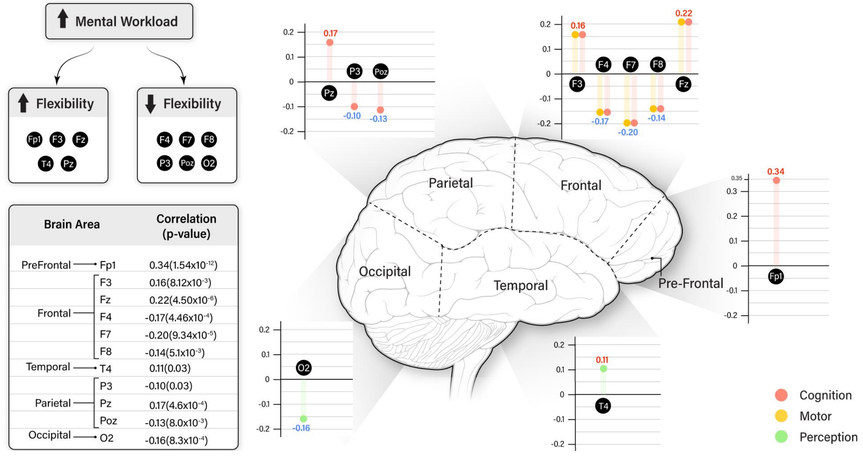
- Utilizing network neuroscience and community detection techniques, network flexibility of 19 brain areas was extracted through each recording
- One channel was corrupted and was discarded from the analyses.

Pearson correlation analysis was performed to find the correlation between mental workload of the subjects and brain network regional flexibility at various brain areas.



Results

- We found significant correlation between network flexibility of most areas of the brain and the MWL value.
- However, we didn't find a significant correlation between average flexibility over all areas of the brain and the MWL (0.03, p=0.56).
- These results show that different areas of the brain have different weights of involvement in the total MWL.
- It is more proper to specify type of MWL as motor, cognitive, and perception MWL to be able to find the involvement of each brain area in specific type of mental workload.



Brain Area		Correlation (p-value)
PreFrontal	Fp1	$0.34(1.54\times10^{-12})$
Frontal	F3	$0.16(8.12\times10^{-3})$
	Fz	$0.22(4.50\times10^{-6})$
	F4	$-0.17(4.46\times10^{-4})$
	F7	$-0.20(9.34\times10^{-5})$
	F8	$-0.14(5.1\times10^{-3})$
Temporal	T4	0.11(0.03)
Parietal	P3	-0.10(0.03)
	Pz	$0.17(4.6\times10^{-4})$
	Poz	$-0.13(8.0\times10^{-3})$
Occipital	O2	$-0.16(8.3\times10^{-4})$

Correlation between mental workload of the subject and the brain network regional flexibility at each brain area.

Conclusion

- Results of this study introduced **brain regional network flexibility** as a feature to be used for evaluation of motor, cognitive, and perceptual mental workloads.
- This novel method identifies level of mental workload types and can also be used to retrieve the reason of overloaded situations.

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