Robotic transcranial magnetic stimulation mapping of the motor cortex in the intact developing brain

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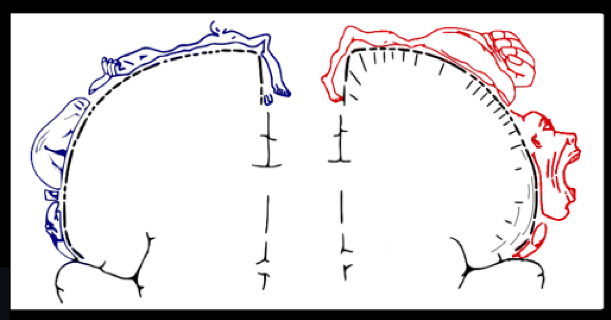
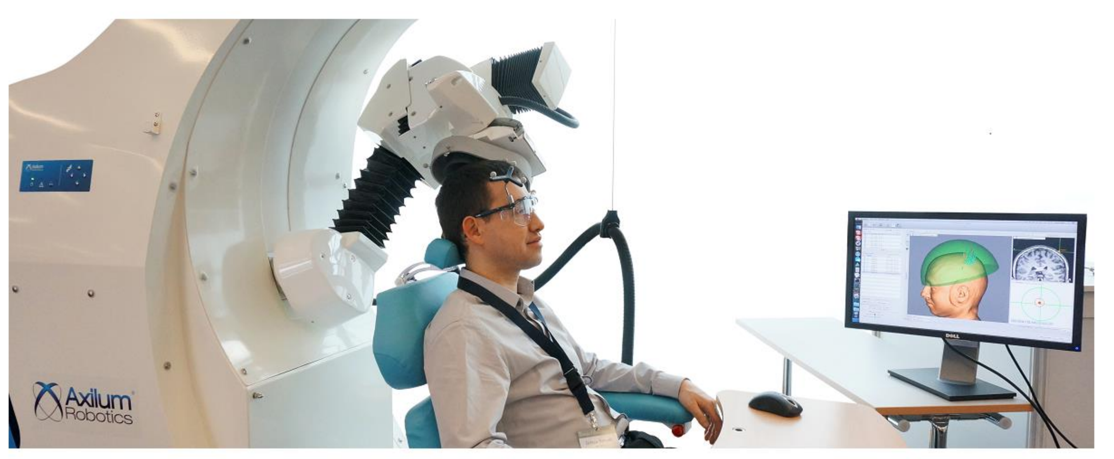
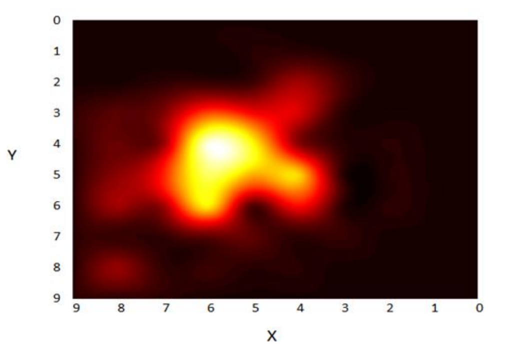
ROBOTIC TMS INTRODUCTION

- Wilder Penfield first described the motor and sensory homunculus in 1950 that showcased the topographic arrangement of muscle representations of the human cortex
- New robot transcranial magnetic stimulation (TMS) technology has been developed to non-invasively assess functional cortical topography *in vivo* (*Axilum robotics, Strasbourg, France*)
- The robot corrects for potential head movement in 3-dimensional space to enhance precision and reproducibility of procedures by eliminating human error – the robot arm features 7 moving joints for improved accuracy
- Here, a study using robotic TMS is undertaken to understand the primary motor cortical M1 representations in healthy pediatric participants





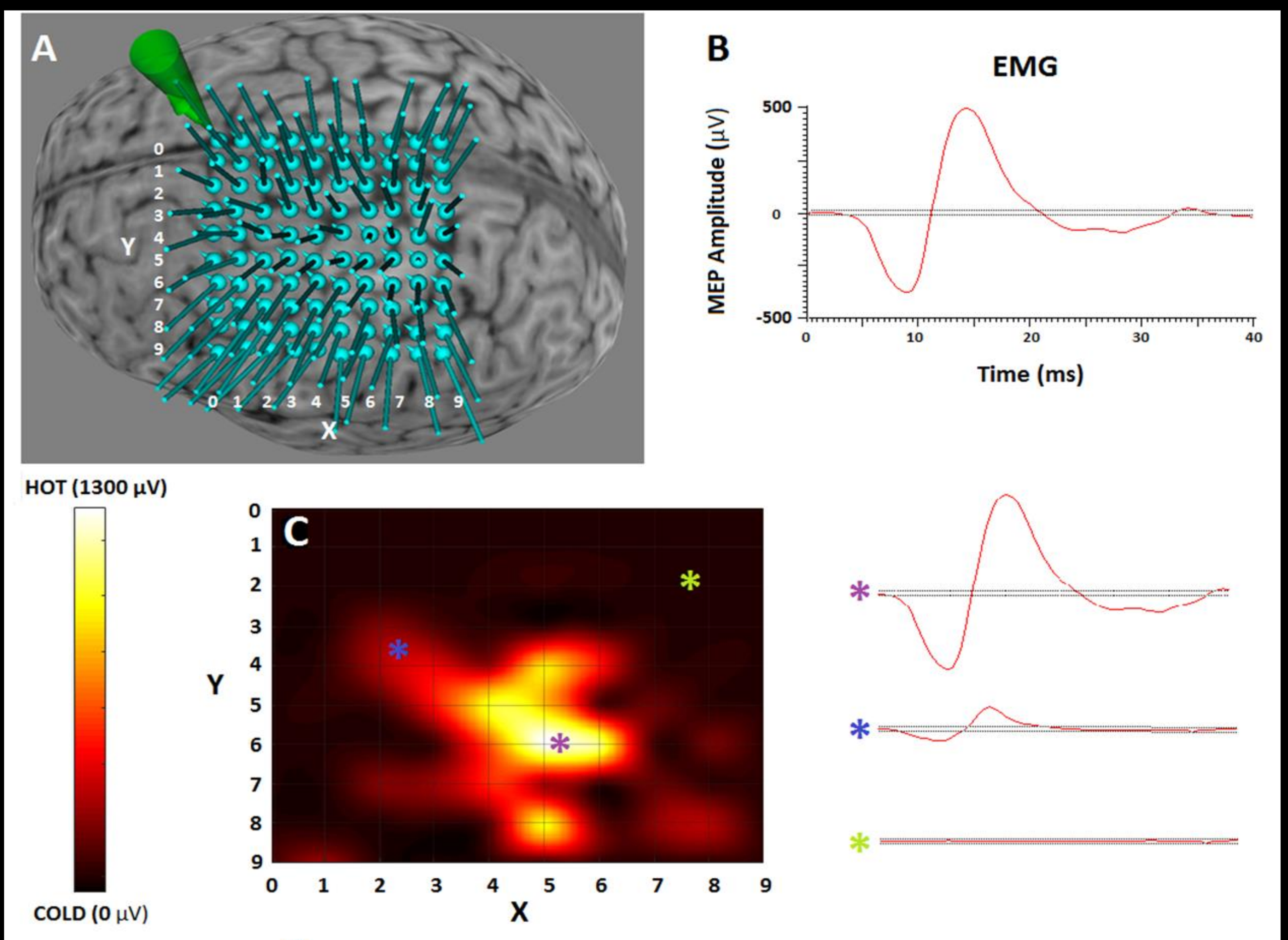


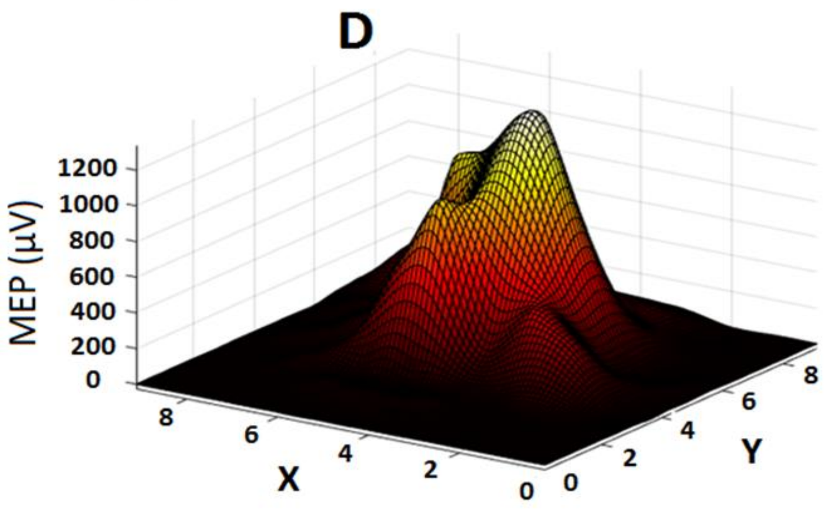
OBJECTIVES

Primary Aim: Determine the feasibility of robotic TMS in a pediatric population and characterize the cortical motor maps in typically developing children

Additional aims:
Localize the mean coordinate of maximal activation (hotspot) and centre of gravity (CoG)
Quantify typical cortical motor map area and volume

METHODS





A: TMS trajectories are pre-defined at coordinate sites on the MRI reconstruction

B: The MEP peak-to-peak amplitude is used in motor map thresholding and quantification

C: MEPs recorded at each coordinate are plotted to generate the cortical motor map

D: Perspective view showcasing MEP amplitude at coordinate locations

METHODS

Patient Enrollment
⇩
Functional Motor Assessment
⇩
Functional Imaging of the Brain
⇩
MRI Processing for Robot TMS
⇩
Patient Arrival and Registration with the Robot
⇩
TMS Threshold Determination
⇩
Motor Map Derivation

Demographics	Healthy Participants
Recruited Participants	12 (4F)
Excluded Participants	2 (0F, age 8)
Mean Age	14.3 ± 1.0

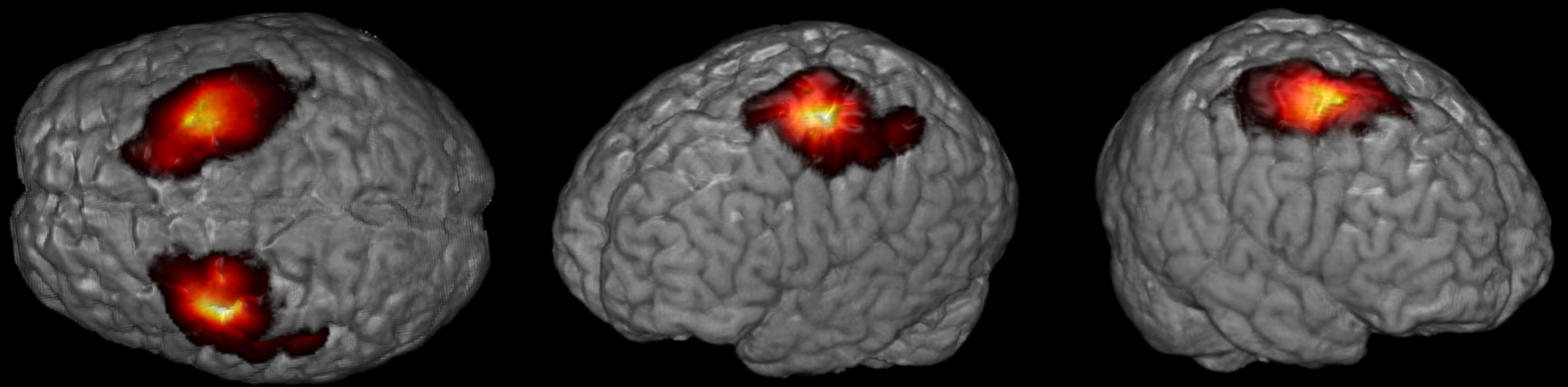
- Surface EMG simultaneously recorded 4 distal forelimb muscles bilaterally, including:
  - first dorsal interosseous (FDI)
  - abductor pollicis brevis (APB)
  - abductor digiti minimi (ADM)
  - abductor pollicis longus (APL)
- The site generating an MEP of maximal amplitude ≥50 µV on ≥5 /10 single pulses was used to find the resting motor threshold (RMT)
- Motor mapping involved delivering 4, 1 Hz single pulses at 120% RMT at each site
- A responsive site was defined as a site generating an MEP ≥50 µV on ≥2 /4 pulses
- Motor map bordering consisted of surrounding the hotspot and all responsive sites entirely by non-responsive sites
- The CoG is an MEP amplitude weighted mean coordinate position of the map, calculated as follows:

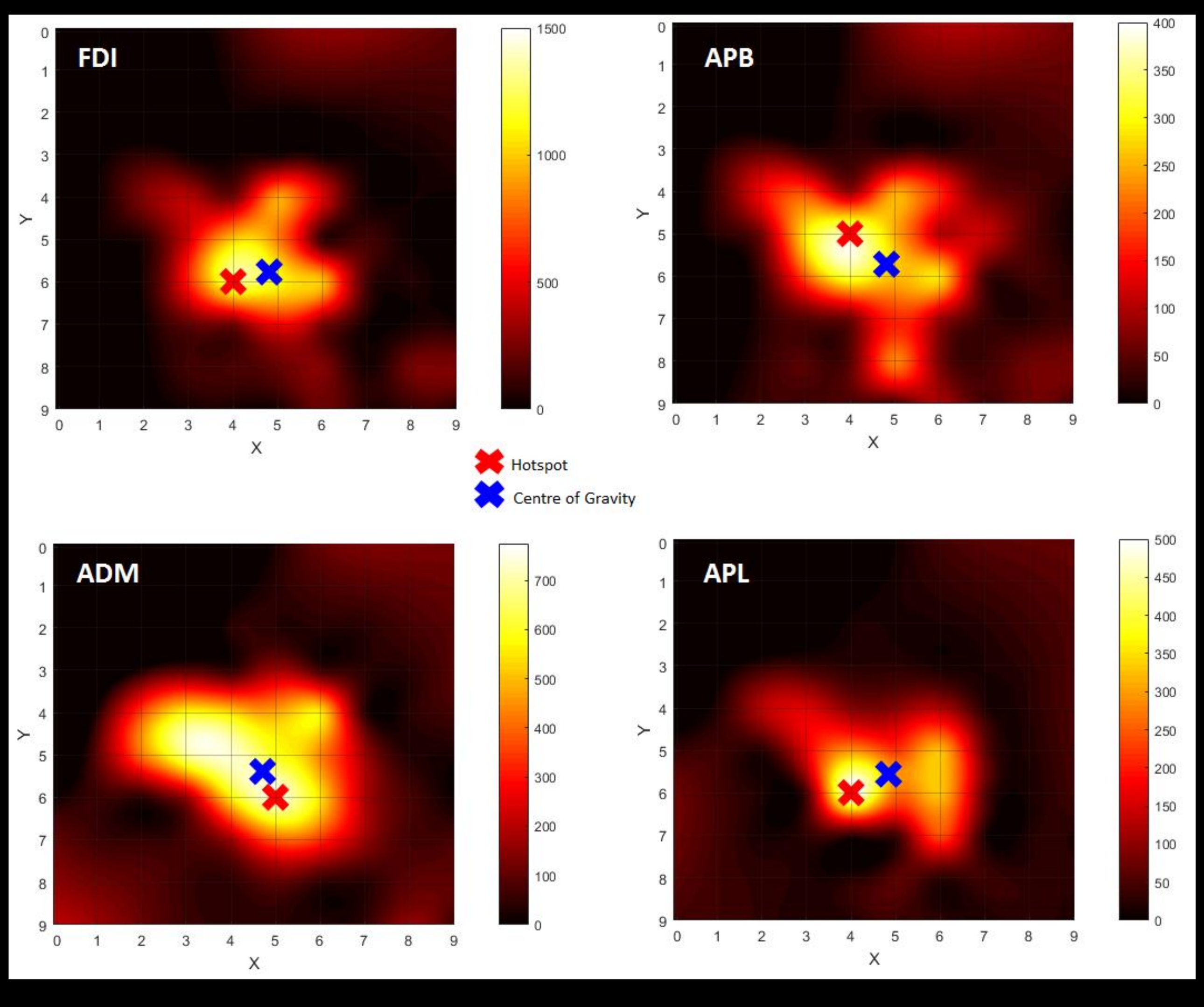
$$xCoG = \frac{\sum(x \cdot aMEP)}{\sum aMEP}, \quad yCoG = \frac{\sum(y \cdot aMEP)}{\sum aMEP}$$

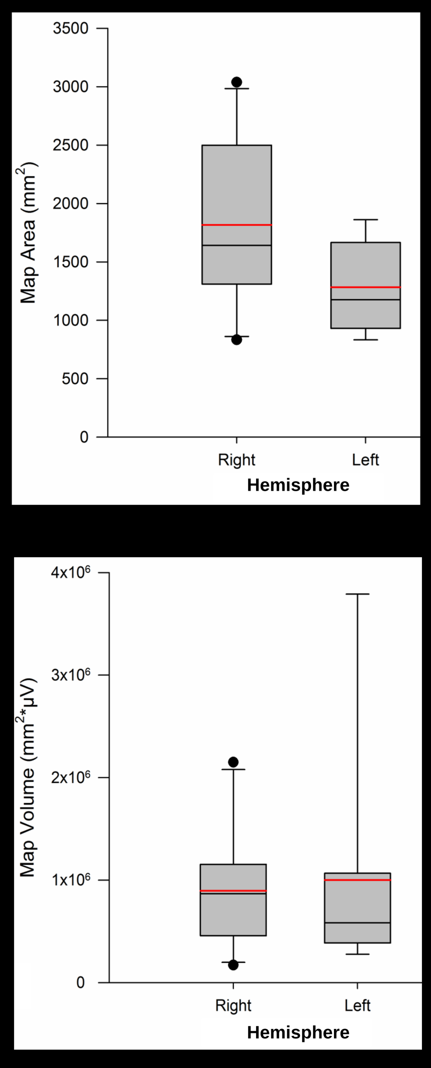
RESULTS

Mean TMS Coordinate Localizations of the FDI Muscle Warped to MNI Space

		X	Y	Z
Left Hemisphere	Hotspot	-37	-12	58
(n=8)	Centre of Gravity	-35	-16	61
Right Hemisphere	Hotspot	43	-15	57
(n=8)	Centre of Gravity	43	-15	58







Top: Mean TMS coordinate localizations of the FDI muscle and representative anatomical MRI reconstructions with derived cortical motor map representations of left and right hemisphere FDI muscles.
Bottom Left: Same representative participant's four left hemisphere motor map representations with the hotspot and CoG plotted (MEP amplitude in µV).
Bottom Right: Quantification of cortical motor map area (mm²) and volume (mm²·µV) of the right (n=9) and left (n=10) hemisphere (red lines indicate means).

- No significant correlation between functional motor assessment score on the Perdue Pegboard Test and map area or volume for both hemispheres.

SIGNIFICANCE

- High resolution cortical motor maps can be generated in pediatric participants using robotic TMS
- Localization of the primary motor cortex in individual children will enable personalized precision targeting for neuromodulation
- Motor map quantification in children with brain injury will better inform clinicians of plastic reorganization and regions of altered excitability

FUTURE DIRECTIONS

- Robotic TMS motor maps will be co-registered with fMRI-derived activation maps to understand the spatial congruency between modalities
- Robotic TMS motor maps will be used as an outcome measure for motor neuromodulation interventions in both normal and hemiparetic children

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