User Testing for Performance and Brain Engagement with the HOPE Hand Exoskeleton for Individuals with Spasticity due to Brain Injury

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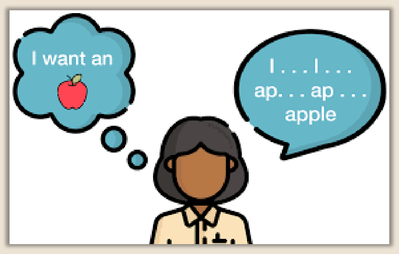
Motivation

Following an upper motor neuron injury, like stroke or traumatic brain injury, individuals may exhibit hemiparesis and subsequent hand impairment, in addition to speech aphasia. The use of an assistive hand exoskeleton, meant to help the user perform activities of daily living (ADL), leverages the principals of neuroplasticity regarding increased frequency of use and increased specificity in doing functional tasks, to further improve neurorehabilitation [1].

TARGET USER CHARACTERISTICS

"80% of people with Broca's aphasia also have hemiplegia" and these conditions "don't just coexist, they interact" [2]

Broca's Aphasia (expressive aphasia)



Hemiparesis (spasticity & hypertonicity)



Evidence suggests that **motor and speech rehabilitation may have positive effects on each other** [2]



GOAL: To evaluate individuals' ability to perform functional tasks with an exoskeleton designed to accommodate spasticity, and to record their brain activation during use. To conduct this study, an exoskeleton capable of extending the fingers of individuals with spasticity was needed. The presented hand exoskeleton and user study lay the groundwork towards demonstrating that daily use of hand exoskeletons may also have neurorehabilitative benefits.

fNIRS Analysis

fNIRS measures changes in the concentration of oxygenated (HbO) and de-oxygenated hemoglobin (HbR) in the brain as a proxy for brain activation.

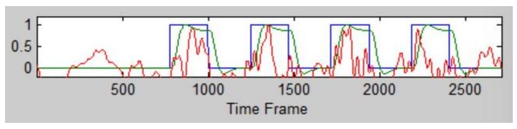
Neural activation
↓
Metabolic demand
↓
Increased blood flow
↓
Increase **in oxy-hemoglobin**
&
Wash-out (decrease) of **deoxy-hemoglobin**

Preprocessing

- Define task blocks Rest vs. Active states
- Data Quality <20 CV%
- Removal of spike artifacts
- Bandpass filtering (.005-.17Hz)
- Calculate hemodynamic states (HbO, HbR)

Level 1 statistical parametric mapping is calculated using a general linear model (GLM). The brain data (deoxygenated hemoglobin) is then displayed using a color gradient.

Simple Block Paradigm

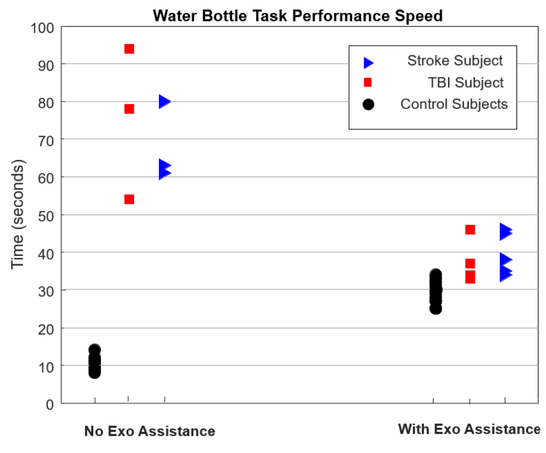


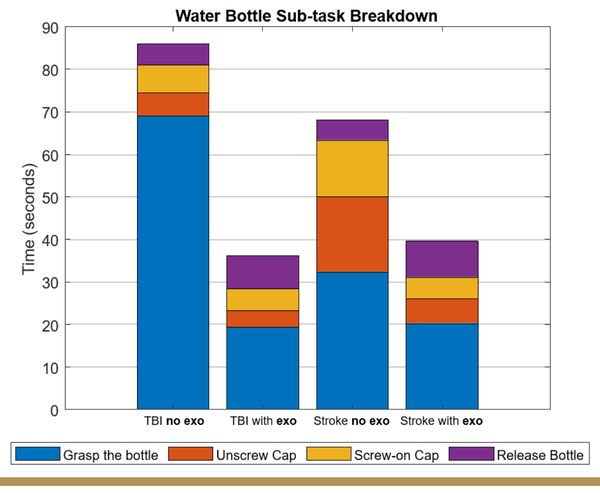
Blue – Task Design,
Red – Averaged Data,
Green – Convolved GLM

Performance Results

Impaired subjects performed the functional water bottle task in significantly less time with the exoskeleton than without it. With exoskeleton assistance, the control subjects and impaired subjects performed similarly in speed. The exoskeleton was the most helpful in the grasping the bottle and unscrewing subtasks.

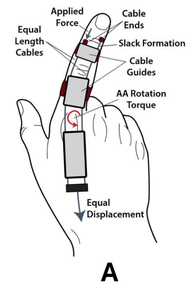


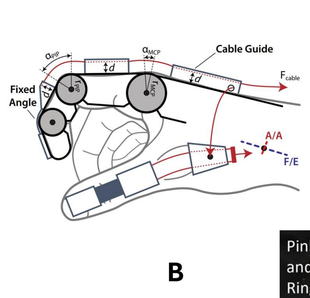




Methods

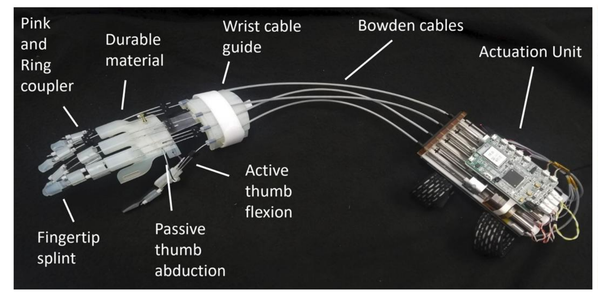
Hand Orthosis with Powered Extension (HOPE Hand)

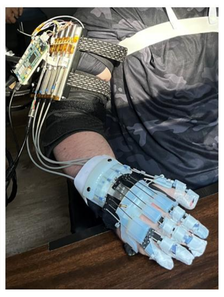




Flexion/Extension (FE) of the fingers and the thumb provided by pushing and pulling cables running along their dorsal surface.

- Weighs approximately 1 kg
- Can provide individuated finger motion with **up to 0.75 Nm of torque at the finger joints for finger extension**
- Can perform finger flexion to accomplish conformable power grasps with the relieving of extension forces and the user's spasticity to close the hand.





Wizard-of-Oz Voice Control:
Users said "open" and "close" commands while a researcher manually operated the open and close input using a graphical user interface (GUI) behind the scenes.

EXPERIMENTAL DESIGN

A study was conducted on 3 control subjects and 2 subjects with spastic hand impairment and Broca's Aphasia due to upper motor neuron injuries. All subjects performed hand movement tasks with and without the voice-controlled HOPE Hand exoskeleton.

Subject Demographics

Subjects	Gender	Age	MAS*	DASH**	Condition	Since Injury
1	F	28	3	57	TBI	9 years
2	M	32	3	44	Stroke	3 years
Controls	1F/2M	22±.5	-	-	-	-

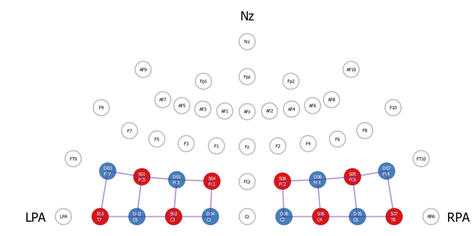
*Modified Ashworth Scale, **Disability of Arm, Shoulder, and Hand

Task List

1. Hand Open & Close – No Assist
2. Water Bottle Task – No Assist
3. Hand Open & Close – Exo Assist
4. Water Bottle Task – Exo Assist



- Tripod for cable tension relief
- Laser optodes with MRI fiducials
- fNIRS Cap
- HOPE Hand Actuation Unit
- HOPE Hand Exoskeleton
- Water bottle prop
- PC with HOPE Hand Control GUI



Control subject wearing HOPE Hand and a NIRScout (NIRx) fNIRS cap (left), optode placement shown in montage (above).

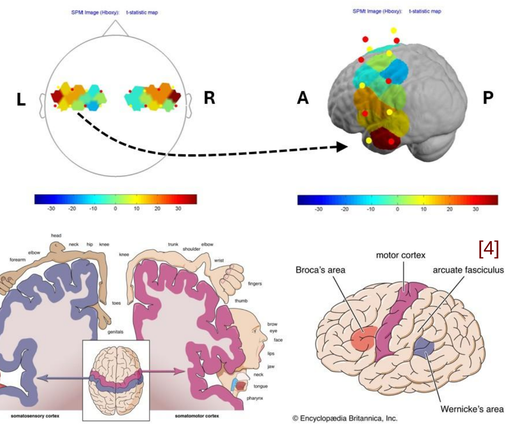
Neuroimaging Results

Neuroimaging can provide insights into brain activation and engagement in tasks, with implications for neurorehabilitation.

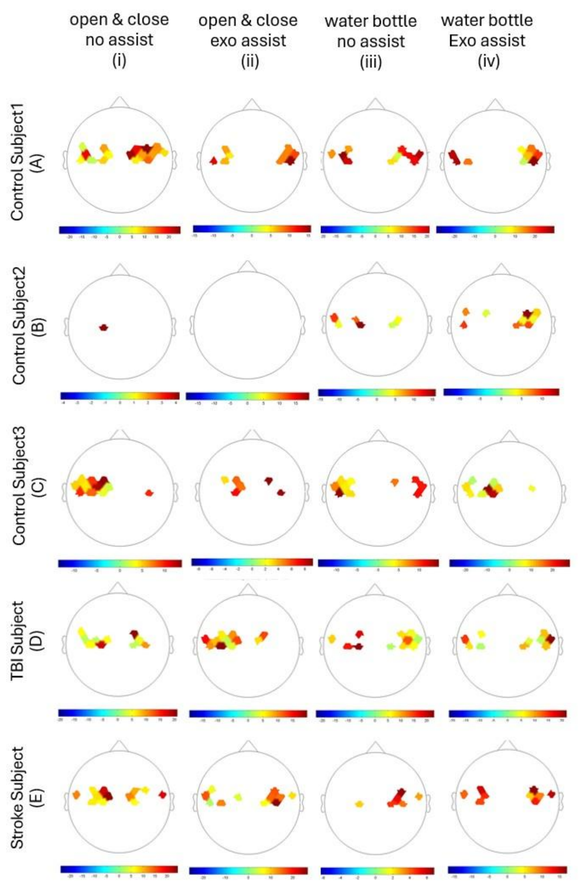
Statistical Parametric Mapping (SPM) → The colored locations on each head represent significant brain activation ($p<0.05$) measured as changes in de-oxygenated hemoglobin during the task.

The fNIRS data showed that subjects' motor cortex and speech centers of the brain were activating despite sustaining damage.

Contextualizing Brain Data



Assumption: The montage provides adequate coverage and that activation would occur in the expected areas according to a standard brain atlas.



Conclusions, Future Work, & Questions

- The HOPE Hand exoskeleton can successfully open/close the hand in **the presence of increased muscle tone (MAS ≥2).**
- The HOPE Hand can assist the user in accomplishing functional bimanual tasks such as opening a water bottle.
- Demonstrated that **robust voice recognition is a feasible user interface** for individuals who have speech aphasia.
- Brain activation was seen in the speech production centers of the brain which could have future rehabilitative benefits.

By **combining performance metrics and neuroimaging**, we can further evaluate the HOPE Hand and other assistive exoskeletons to study their **potential for promoting neurorehabilitation through increased purposeful hand engagement**. In the future, we'd like to conduct a longitudinal study assessing brain activation patterns over time and rehabilitation progress.

Limitations/Lessons:

- Challenging to interpret individual subject's fNIRS data
- Small sample size
- Longitudinal study needed to assess effect of voice-controlled assistive exoskeleton use on rehabilitative outcomes

Please contact Tess Meier at tbmeier@wpi.edu to connect regarding this work.

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References

[1] L. Bonanno, et al. Neural plasticity changes induced by motor robotic rehabilitation in stroke patients: the contribution of functional neuroimaging," Bioengineering, vol. 10, no. 8, p. 990, 2023. **[2]** Anderlini, D. et al. (2019). Language as a predictor of motor recovery: the case for a more global approach to stroke rehabilitation. Neurorehabilitation and Neural Repair, 33(3), 167-178. **[3]** S. N. Kapusta, homunculus. Encyclopædia Britannica.**[4]** left hemisphere of the brain. Encyclopædia Britannica, Inc.