Enhancing Upper Extremity Rehabilitation in Neurodiverse Children: BCI-Mediated Neurofeedback and Virtual Reality for Improved Engagement and Training Quality

Project Description/Background:
Cerebral palsy (CP) is the most common childhood motor disability and frequently results in impaired upper-limb coordination and reduced bimanual function (Aisen et al., 2011). Hand-Arm Bimanual Intensive Therapy (HABIT) is an evidence-based intervention designed to improve functional use of the affected upper limb through structured, repetitive, goal-directed practice (Figueiredo et al., 2020). Virtual reality (VR) adaptations of HABIT have been developed to increase engagement and training intensity while preserving these therapeutic principles (Gehringer et al., 2022). Building on HABIT-VR, the BCI-HABIT-VR approach incorporates a brain–computer interface (BCI) that uses electroencephalography (EEG) to record cortical activity associated with movement intention. In this paradigm, the child's brain activity is analyzed in real time to detect motor intent and trigger in-game actions, directly linking movement intention with task execution during rehabilitation (Elashmawi et al., 2024).

Data for this project were collected during a two-week (10-day) summer virtual reality rehabilitation camp for children with cerebral palsy. Eight participants were divided into two intervention groups: HABIT-VR and BCI-HABIT-VR. Both groups completed daily VR-based bimanual training sessions based on HABIT principles. In the BCI-HABIT-VR group, participants wore an EEG system during gameplay, and cortical activity related to movement intention was recorded and analyzed in real time. Detected motor intent was used to interact with the VR game, effectively connecting the participant's brain activity to game events. All participants completed standardized pre- and post-intervention assessments, including video-recorded task performance, the Assisting Hand Assessment, and the Box and Block Test. The current project involves secondary analysis of these existing data, with no new data collection.

Project Significance:
This study is significant because it evaluates whether incorporating a brain-driven control element into VR-based bimanual training is associated with measurable differences in upper-limb functional outcomes following a short, intensive intervention. Using previously collected data from eight children with CP, this project examines both within-participant improvements after a two-week summer camp and between-group differences between HABIT-VR and BCI-HABIT-VR. Functional outcomes are assessed using complementary measures: the Box and Block Test, which captures manual dexterity and motor capacity (Zapata-Figueroa & Ortiz-Corredor, 2022), and the Assisting Hand Assessment, which reflects spontaneous bimanual performance during functional activities (Krumlinde-Sundholm et al., 2007). By comparing these outcomes across intervention types, this study will help clarify whether linking brain-derived motor intent to task execution influences functional gains and outcome sensitivity. The findings will inform the design and evaluation of future technology-assisted pediatric rehabilitation interventions.

Hypothesis:
We hypothesize that participation in a two-week virtual reality–based bimanual training camp will lead to measurable improvements in upper-limb function in children with cerebral palsy, as reflected by video-coded task performance, the Assisting Hand Assessment (AHA), and the Box and Block Test (BBT). We further hypothesize that children who participated in BCI-HABIT-VR, in which brain-derived motor intent is connected to game interaction, may demonstrate greater or different patterns of functional improvement compared to those who participated in HABIT-VR alone.

Aim 1 — Evaluate within-participant changes in upper-limb function following the summer VR camp. To quantify pre- to post-intervention changes in upper-limb functional performance across all eight children with cerebral palsy, regardless of group assignment, using video-coded outcomes, AHA scores, and BBT

scores. We hypothesize that the participants will show significant improvements in upper-limb function following the two-week intervention across all outcome measures.

Aim 2 — Compare functional outcomes between HABIT-VR and BCI-HABIT-VR groups. To compare pre-to-post changes in upper-limb function between children who participated in HABIT-VR and those who participated in BCI-HABIT-VR, using change scores from video coding, AHA, and BBT. We hypothesize that both groups will demonstrate functional gains, with potential differences in the magnitude or pattern of improvement between intervention groups.

Methods:
This study will employ a retrospective, secondary-analysis design using previously collected data from a two-week (10-day) summer virtual reality rehabilitation camp for children with cerebral palsy. Eight participants were assigned to either a HABIT-VR or BCI-HABIT-VR intervention group and completed daily VR-based bimanual training sessions grounded in HABIT principles. All participants underwent standardized pre- and post-intervention assessments, including the Box and Block Test (BBT) (Zapata-Figueroa & Ortiz-Corredor, 2022) and the Assisting Hand Assessment (AHA) (Krumlinde-Sundholm et al., 2007). BBT performance was video recorded to allow accurate counting of the number of blocks transferred during each trial, ensuring consistency and verification of scoring. In addition to standardized assessments, behavioral video coding will be conducted using approximately 120 minutes of HABIT-VR training footage per child, randomly selected from sessions collected during the summer 2025 camp. Videos will be coded using a structured rubric in ten-second intervals to document the presence of bimanual use, participant engagement, therapist assistance, and negative or neutral behaviors. The undergraduate researcher will be trained in video coding and assessment scoring under faculty supervision, and a subset of videos will be double-coded to evaluate inter-rater reliability (Skorup et al., 2024). Pre-to-post changes in functional outcomes will be analyzed across all participants, and between-group comparisons will be conducted using change scores from video-coded measures, AHA, and BBT, with effect sizes reported to contextualize findings given the small sample size.

Student and Faculty Mentor Roles:
The undergraduate student will process and analyze previously collected outcome measures to evaluate changes in upper-limb function following participation in the summer VR camp. Under the guidance of the faculty mentor, the student will work with video-coded measures, the Assisting Hand Assessment, and the Box and Block Test to organize data and support statistical analyses. The faculty mentor will oversee all aspects of the project, including training, methodological rigor, data interpretation, dissemination of the results, and responsible conduct of research, while providing regular feedback and mentorship throughout the study.
Deliverables: The project will result in (1) a curated dataset of processed outcome measures, (2) a summary of within-participant and between-group results, (3) at least one undergraduate research poster suitable for presentation at a university research forum, and one suitable for a national scientific conference such as AACPDM.

Proposed Timeline:

Timeline	Details
May 2026	Meet with faculty mentor to finalize analysis plan, begin behavioral video coding of HABIT-VR and BCI-HABIT-VR sessions
June 2026	Complete behavioral video coding, assess inter-rater reliability, organize pre-and post-intervention assessment data (AHA and BBT)
July 2026	Analyze within participant pre- to post-intervention changes and within group changes, calculate effect sizes, interpret findings, create research poster.
August 2026	Finalize poster and present findings

Budget and Justification:
I would like to request a stipend of $2,000 to compensate for my time and labor in completing this project. For 13 weeks from May to August, I plan to dedicate approximately 10 hours per week to behavioral coding, assessment scoring, data analysis, and meetings with my faculty mentor, at a rate of $15 per hour.

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University of Nebraska Omaha

DEPARTMENT OF BIOMECHANICS

January 4th, 2026

Letter of Mentor Support for Madeleine Alexander- Fund for Undergraduate Scholarly Experience (FUSE)

Dear Members of the FUSE Review Committee,

I am writing to express my strong support for Madeleine Alexander's application to the Fund for Undergraduate Scholarly Experience (FUSE). I serve as Madeleine's faculty mentor in the Department of Biomechanics, where she has been an integral member of my research team focused on pediatric neurorehabilitation and virtual reality-based interventions.

Madeleine has played a critical role in the successful execution of our summer BCI-HABIT-VR camp, where she was deeply involved in day-to-day camp operations, participant interaction, and data collection. Her contributions were essential to maintaining the consistency, safety, and quality of a demanding clinical research environment involving children with cerebral palsy. She has already demonstrated a strong understanding of clinical research workflows and has contributed meaningfully to the development and implementation of our BCI-HABIT-VR system.

Madeleine is currently an undergraduate student majoring in Neuroscience with a minor in Biomechanics, a combination that uniquely positions her for applied human movement research. She has completed the necessary training to analyze and perform standardized behavioral video coding, including applying structured coding rubrics to footage of rehabilitation tasks. She is exceptionally punctual, reliable, and detail-oriented—qualities that are indispensable in clinical research settings. Beyond her strong work ethic, she is highly driven, intellectually curious, and a fast learner. Her clear interest in pursuing physical therapy is reflected in her enthusiasm for patient-centered research and functional outcome assessment.

Through the proposed FUSE project, Madeleine will further develop her skills in processing and analyzing standardized outcome measures used in pediatric rehabilitation research, while gaining structured mentorship in research methodology, data interpretation, and scholarly dissemination. My role will be to provide close supervision and guidance throughout the project, ensuring methodological rigor while fostering Madeline's growth as an independent and thoughtful researcher. She will have full access to all necessary laboratory resources, datasets, and mentorship support required for successful project completion.

I am fully committed to mentoring Madeleine throughout the duration of this project and strongly believe that FUSE support will have a meaningful impact on her academic and professional development. She possesses the motivation, maturity, and clinical curiosity necessary to make the most of this opportunity, and I enthusiastically endorse her application. Thank you for your consideration.

Sincerely,

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