Identifying Independent Components of Mobile Brain Imaging

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Electroencephalography (EEG) is becoming a powerful tool for mobile brain imaging research because it enables real-time, noninvasive monitoring of electrical brain activity with high temporal resolution. EEG acquired during active human motion is usually contaminated with a variety of unwanted signals such as muscle, eye, and cardiac signals that have to be separated from the signal of interest. Independent component analysis (ICA) is one method that can be used to separate brain activity from high-amplitude motion and muscle artifacts. Independent components found using ICA can be visually inspected, selected, and interpreted, but this requires extensive time and expertise. Alternatively, automated classifiers can be used to broadly categorize independent components, reducing time spent analyzing EEG data and increasing replicability across research labs. While many such classifiers have been developed [1-7], their underlying models rely on stationary EEG data, which does not fully represent the data content of mobile EEG studies. Our objective is to design a classifier using data from mobile EEG recordings that will automatically categorize neural and artificial components. We hypothesize that a classifier trained on mobile EEG data will improve the accuracy of independent component label estimates when compared to the best publicly available automated independent component classification method.

We are collecting a training set of mobile EEG data that will be used to train the classifier. We invite researchers to submit their MoBI datasets to contribute to training a robust classifier (see further project details here: https://faculty.eng.ufl.edu/human-neuromechanics-laboratory/projects/). To increase robustness, we aim at including datasets from many labs with a wide range of experimental protocols. All data sets should contain human subjects performing tasks with whole body movement with a minimum channel density of 64 electrodes for more accurate source localization [8,9]. Other inclusion criteria include participants that are neurologically intact, older than 12 years of age, and have normal or corrected to normal vision. Studies that include participants with neurological or locomotor (muscular/musculoskeletal) deficits (e.g., Parkinson's disease, multiple sclerosis, post-stroke hemiparesis, spinal cord injury, cerebral palsy) will be excluded. Further requirements for the data to be included can be found on the project website.

We will use an artificial neural network (ANN) to develop our ICMoBI (Independent Components of Mobile Brain Imaging) classifier as they are particularly useful for complex pattern recognition and classification. Supervised training of this classifier requires a training set of ICs that have corresponding labels. To create this training set, we will be collecting IC labels from users on the ICMobI website, which will be our crowd labeling platform, similar to Pion-Tonachini et al. (2019)[5].To train our classifier, we will select features that will capture both spatial and temporal characteristics of each component: scalp topography, dipole location, power spectra, cross-frequency power coupling, as well as time-domain features (root-mean square, mean absolute value, waveform length, variance, standard deviation). Principal component analysis will be used to reduce the dimensionality of the feature set. The classifier hyperparameters will be tuned using 10-fold cross validation on the training set. Classifier performance will be evaluated using an expert-labeled test set built using datasets that were not included in the training set (i.e., the IC's used for training and testing were from different ICA decompositions). Our goal in creating this classifier is to reduce component analysis time and subjectivity in component selection for researchers involved in mobile EEG research and to extend the range of existing IC-labels from stationary protocols to a wider range of IC-labels, including movement-related ICs as reported in previous MoBI studies [10]. Preliminary results will be presented at MOBI 2022.

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Immersive Virtual Environments and Physical Built Environments: Consistent cognitive performance and physiological metrics

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The idea of rigorously studying behavioral patterns and hard data to investigate human responses to design has been around for many years, but it is only recently that this approach has consolidated into the widely recognized paradigm known as evidence-based design (EBD) (Hamilton & Watkins, 2009; Kalantari & Snell, 2017). Rigorous post-occupancy studies are an important part of this process. However, post-occupancy studies in evaluating these human outcomes have important limitations, from upfront construction cost to reduced flexibility in design changes. This limits our ability to collect reliable data on alternative design possibilities. In addition, the uniqueness of each building and architectural setting presents challenges for isolating design variables and rigorously comparing them against other possible designs. To address these challenges, our team has developed a virtual-reality testing environment, coupled with human physiological measurements and cognitive tests to evaluate the effect of different design elements on human response at the behavioral, self-reported, and physiological level (Kalantari et al. 2018). The platform collects physiological measurements, including head motion, brain activity using EEG, heart rate, and galvanic skin response (actiCHamp and accessories, Brain Products, GmbH), and synchronized response tracking within the platform.

While behavioral data suggest that performance is similar in immersive virtual and physical environments (Heydarian et al. 2015), more evidence is needed for physiological markers within both environments. Here, we evaluated participants' multimodal responses in a real classroom setting and compared them to their responses in a virtual-reality immersive representation of the same classroom. A classroom was 3D scanned and reconstructed in immersive virtual reality for behavioral, self-reported, and physiological comparison between these conditions. To evaluate cognitive performance and the associated physiological responses, we used standard memory and attention tests: Benton visual retention test, the checkerboard spatial memory test, the Stroop interference test, digit span test, and an arithmetic test. Thirty-five healthy human adults with normal or corrected-to-normal vision were recruited for the study.

No major differences were found for test accuracy performance, eye blink rate, heart rate, or GSR patterns between the virtual reality and the real classroom conditions. The EEG data showed significant differences ($p < 0.01$) in measured bandpower in fronto-temporal electrodes in the delta and theta bands (1-8 Hz). These significant differences were sparse and limited to a few peripheral electrodes, suggesting that EEG data was not significantly disturbed with the change of testing environment in the gross band-power analysis. Distinct event-related potential patterns were found for each test, without major differences between the real built environment and the virtual reality environment. The Stroop test showed more pronounced event-related potential peaks post-response, suggesting that visual processing and feedback could have been more effective in the virtual reality setting. The heart rate response was kept consistent among all tests and conditions with a median of 60±4 beats per minute. The GSR activation patterns were consisted across the built environment and the virtual reality conditions, with high peaks of activity in the tonic GSR at the beginning of each test, followed by smaller peaks after each input response with feedback. The GSR levels were highest at the start of the whole sequence of tests with the Digit Span memory test, the Arithmetic test, and lower for the Stroop, Benton, and the checkerboard visual memory tests.

These results validate the use of immersive virtual reality environments in the study of cognitive performance. The physiological responses of participants did not diverge significantly in the virtual reality immersive representation of a real-world classroom. Test accuracy performance did show improvement in the virtual reality environment, particularly for the Benton visual retention test, the Stroop test and the checkerboard spatial memory test: those tests that required visual divided attention, and spatial memory. Importantly, this study was possible due to synchronization tools that allowed the collection of different streams of data through the lab streaming layer (Kothe 2015) and custom software for response input and synchronized video recording. The effectiveness of EEG measurements both in real-world and immersive virtual reality settings provide evidence for the further exploration of the effect of different design elements in human behavioral, self-reported, and physiological performance in the analysis of cognitive tasks.

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2 Mobile SSVEPs of real-world environments with LCD glasses

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At the 2020 MoBi conference we presented a proof of concept study demonstrating visual flicker with LCD glasses as a method for mobile EEG (Dowsett et al. 2020). Visual flicker produces so called steady state visually evoked potentials (SSVEPs), which are normally presented to stationary participants on computer screens. Here we demonstrated SSVEPs of real world scenes during walking with the LCD glasses. SSVEPs generated with this method have a number of advantages: firstly the excellent signal to noise ratio overcomes the problem of motion artifacts, even in setups with a small number of electrodes. Secondly, SSVEPs can be created from whatever the participant is looking at, essentially frequency tagging the real world. Thirdly, SSVEPs can be generated at any frequency, which is not possible in screen based paradigms.

Here we present data from a series of subsequent experiments which demonstrate some of the ways in which this method can be applied.

1 - Mobile SSVEPs in the gamma band. Here we collected 64-channel EEG while participants were either walking or standing, with the LCD glasses flickering at a range of frequencies in the gamma band. Phase shifts when walking (relative to standing) can be seen in the SSVEPs in the gamma band. High frequency flicker with LCD glasses (30 – 60 Hz) has a significant advantage for mobile EEG because the visual flicker is not obvious, and at higher frequencies not perceptible at all, and is not uncomfortable or a significant distraction from any task the participant might be engaging in.

2 - Mobile SSVEPs in a variety of different real world settings. In this experiment participants were walking at various speeds in two distinct environments: down a long corridor which was lit by artificial light in one condition, and across an open space lit with natural light (a lobby with large windows) in another condition. Distinct SSVEPs in the gamma band (in terms of phase and amplitude) can be observed depending on the environment, and

walking and standing can be dissociated in both environments. This demonstrates the robustness of the method to the variable visual properties of different real-world spaces (luminance, size of space etc.).

3 - Combined LCD glasses and eye-tracking. In this experiment participants were wearing a head mounted eye-tracker (pupil labs) and the LCD glasses. The glasses were providing flicker in either the alpha or gamma range (10 and 40 Hz). We demonstrate that eye-tracking data can be synced with the flicker such that separate SSVEPs can be generated depending on what, or who, the participant is looking at. Here we frequency tag individual people during natural viewing in social setting, and demonstrate that distinct SSVEP waveforms can be observed depending on whether the participant is looking at a person or not.

In each if these studies the signal-to-noise ratio of the SSVEPs was calculated to demonstrate that the head, body and eye movement artifacts were successfully removed (as in Dowsett et al. 2020), and were not distorting the signal . Control conditions were carried out with the same setup, but with the LCD glass covered with black cardboard, so the participant could not see any flicker. This was done to identify and remove any artifacts resulting from the glasses themselves.

These experiments together demonstrate that mobile SSVEPs with LCD glasses are a promising solution for EEG in the real world. This method is able to overcome the problem of motion and eye-movement artifacts in a setup with a small number of electrodes. This could be combined into a discreet setup that could be worn in everyday settings (although large numbers of electrodes are also an option for lab based studies). The high frequency flicker is not distracting, and is no more inconvenient than wearing a pair of sunglasses. The combination with modern head mounted eye-trackers, which can also fit into the frame of normal eye-glasses, is a promising avenue for EEG research with participants actively interacting with their environment and/or with other people.

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3 Tracking User Experience in VR using Neural Interface Technology

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Neural interfaces hold significant promise to track user experience implicitly. Their application in VR/AR simulations is especially favorable as it allows user assessment without breaking the immersive experience. In VR, designing immersion is one key challenge. Subjective questionnaires are the established metrics to assess the effectiveness of immersive VR simulations and rendering hardware. However, administering such questionnaires requires breaking the immersive experience they are supposed to assess.

In this work, we will present research results about a complimentary metric based on multimodal physiological measurements. To validate this new complementary metric, we designed an oddball paradigm in VR. In our experiment, we aim to break the user's sense of presence through visuo-haptic glitches as well as task-irrelevant distractors during a reach-to-tap task. We will use a haptic glove (SenseGlove DK1) to render different levels of haptic immersion: vibrotactile as well as force feedback. Our working hypothesis is, that these violations of the predicted action outcome indicate a disrupted user experience.

To feel present in an environment, users need to establish a dynamic and precise interaction with their surroundings. This allows users to infer the causal structures in the (virtual) world and develop strategies to deal with uncertainties in their dynamic environment. Today, the brain is frequently conceived of as a model of its environment, in the constant game of predicting the causes of its available sensory data. In this predictive coding conception, probabilistic analyses of previous experiences drive inferences about which actions and perceptual events are causally related. This is inherently tied to the body's capacity to act on the environment, rendering the action-perception cycle of cognition into an embodied process. When all movement-related sensory data (i.e., sensorimotor data) are consistent with the predicted outcome of an action, the action is regarded as successful. However, when a discrepancy between the predicted and the actual sensorimotor data is detected, a prediction error occurs, and attention will be directed to this discrepancy to correct an erroneous action in real-time. Therefore, the fast and accurate detection of such discrepancies is crucial to perform precise interactions, in the real as well as in virtual worlds.

In the proposed paper, we will source data from electrodermal activity (EDA), electrocardiography (ECG) as well as electroencephalography (EEG) to extract several neurophysiological features of prediction errros: skin conductance features, heart rate and variability as well as several time and spectral characteristics of event-related EEG activity. This feature space will be fused and employed to predict subjective ratings from the Slater-Usoh-Steed (SUS) presence scale and Immersion Presence Questionnaire (IPQ).

Overall, we aim to show that the features from our leveraged sources reflect violations of user's predictions during interaction with AR/VR, promising a robust and targeted marker for adaptive user interfaces.

4 Sound processing in everyday life: A mobile ear-EEG study

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Environmental sounds, even when they are soft, can disturb and annoy people. They thereby cause stress and contribute to diseases and a reduction in the quality of life (Basner et al., 2014). Yet, not everyone exposed to environmental sounds is annoyed or stressed by them. There are large inter-individual differences: two different people can react very differently to the identical sound. For example, one office worker might be severely distracted by a dripping water faucet, while another worker is unaffected.

To study these inter-individual differences, we are currently (Feb 2022) conducting recordings with smartphone-based mobile electroencephalography (EEG) around the ears (cEEGrids, Bleichner & Debener, 2017; Debener et al., 2015; Hölle et al., 2021) in the lab and in everyday life. Participants are equipped with cEEGrids, a smartphone (Google Pixel 3a) for data recording and stimulus control, the nEEGlace (neckspeaker with integrated EEG amplifier, Bleichner & Emkes, 2020) for sound presentation, and ear-microphones that record the environmental sounds as privacy-aware acoustic features (loudness, RMS; power spectral density, PSD; and sounds onsets) via the AFEx app (Hölle et al., 2022). With this setup, we analyze brain responses to experimental stimuli (presented sounds) and non-experimental stimuli (environmental sounds). Twenty participants are recorded for 4 hours (1 hour lab, 3 hours everyday life).

In the everyday life recording, participants follow their daily activities in an office while they are sporadically presented with sounds. They receive no further instructions. How do they process these sounds? To answer this question, we generate reference conditions of sound processing in the lab that can then be related to the default sound processing of an individual in everyday life. We create three different modes of processing sounds: first, we instruct participants to read and listen to a newspaper article while sounds are presented. The focus lies on the article and the sounds may not be noticed; hence, this condition resembles an unaware processing mode. Second, participants are instructed to passively listen to presented sounds. The sound is noticed, but is not considered as distracting or annoying, resembling an aware but indifferent processing mode. Third, we instruct participants to count rare sounds while ignoring frequent sounds. Participant hence focus on the sounds, similar to what an individual that is disturbed by sounds would do (disturbed processing mode).

For all conditions, we use a paired-click paradigm. Participants are presented with a click pair every 8-9 s, with 500ms between clicks in a pair (Gjini et al., 2011; Shepherd et al., 2016). In 20 % of the pairs, the second click is pitch deviant. In everyday life, participants are presented with bursts of 10 paired clicks (2 deviants) that occur approximately every 5 minutes for a total of three hours (36 bursts). During this time, participants work in an office on their self-chosen activity, such as studying, reading, or watching Netflix. In addition to the presented sounds, we also record the environmental sounds in this condition. The three hours include a brief trip to the cafeteria for lunch. In the lab conditions, participants are continuously presented with paired clicks for 15 minutes. Participants either start with the everyday life or the lab conditions, which was counterbalanced across all participants.

With this paradigm we can, first, study event-related potentials (ERPs) in relation to experimentally controlled sounds (i.e. the presented clicks) and compare the controlled lab conditions to everyday life. Second, we can study ERPs in relation environmental sounds captured by AFEx that are not under experimental control. This provides us with a unique possibility to study sound perception for extended periods of time in everyday live in an individual. We will discuss practical aspects of data recording and the results. With our comprehensive dataset, we hope to gain a better understanding of sound processing in everyday life.

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5 Crowdsourced EEG Experiments: A proof of concept for remote EEG acquisition using EmotivPRO Builder and EmotivLABS

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Online research platforms have enabled mass data collection enabling representative samples for cognitive behavioural studies. However, the benefits of online data collection have not been available for cognitive neuroscience fields such as electroencephalography (EEG). In this study, we introduce an approach for remote EEG data collection. We demonstrate how an experiment can be built via the EmotivPRO Builder and deployed to the EmotivLABS website where it can be completed by participants who own EMOTIV EEG headsets. To demonstrate the data collection technique, we collected EEG while participants engaged in a resting state task where participants sat with their eyes open and then eyes closed for two minutes each. We observed a significant difference in alpha power between the two conditions thereby demonstrating the well-known alpha suppression effect. Thus, we demonstrate that EEG data collection, particularly for frequency domain analysis, can be successfully conducted online with remote users.

6 EmotiBit: An open-source multi-modal sensor for capturing research-grade physiological signals from anywhere on the body

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Sitting at the nexus of brain and behavior, peripheral physiological signals provide a powerful window toward understanding central nervous system dynamics, in particular how our intentions and emotions shape our actions and reactions to the world around us (Picard, 2000). However, the available peripheral physiology devices have a number of roadblocks that create challenges for utilizing their data. One the one hand, consumer-grade devices like the FitBit and Apple Watch are easy to wear (at least on the wrist) but provide very limited access to consumer-grade data and black-box signal processing algorithms, which can make it difficult to interpret the data in research contexts (Bernal et al., 2021). On the other hand, research-grade devices (e.g. Empatica, Shimmer, BIOPAC) provide greater access to high-quality data but remain in closed ecosystems at high price points that are out of reach for many. To bridge these advantages and disadvantages of available biometrics solutions, we launched an open-source physiological sensing platform called EmotiBit (http://www.emotibit.com/). EmotiBit can wirelessly stream and locally record data from a multi-modal constellation of sensors, including electrodermal activity (EDA), multi-wavelength PPG, a medical-grade temperature sensor, 9-axis IMU, and a fast-growing list of derivative metrics. The software is open-source to provide a transparent window into the treatment of the data and the data is 100% owned by the user with no remote-server intermediary. Utilizing a flexible hardware design to be compatible with the Adafruit Feather open-source ecosystem, the device can easily pick up physiological signals from nearly anywhere on the body. EmotiBit is compatible with a growing list of output channels (e.g. UDP, TCP, OSC, LSL, MQTT, etc) which makes it easy to connect the data with other devices and tools, and to record from multiple people simultaneously in a social context ('hyperscanning'; e.g. via Lab Streaming Layer).

EmotiBit has been developed through several rounds of alpha and beta partnerships to create features and capabilities that support a multidisciplinary range of perspectives and needs. It's been used by snowboarders in risk-taking studies at the University of Chicoutimi; classrooms at Duke University; Olympic biathletes and mountaineers on Mt. Everest; research labs at NYU, MIT and across the globe; dancers in the New York Electronic Arts Festival (LoVid 2019) and Art-A-Hack collaboration with Battery Dance studio (Thoughtworks Arts, 2020); and at companies ranging from startups to Nike and Apple. As EmotiBit shifts from limited small-batch production to wider availability in spring 2022, we hope to lower the barrier to entry and make research-grade physiological data more accessible with an affordable and extensible open-source platform. At MoBi, we will present live, hands-on demonstrations of EmotiBit, and hope to enter conversations with peers about possible future directions, ongoing validation studies, and how we can build out an ecosystem with the MoBI community to democratize physiological sensing.

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7 Comparison of Human and Phantom Motion Artifacts

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Motion artifact is a persistent problem in mobile electroencephalography (EEG) research. Large signal disruptions caused by electrode motion on the skin make it difficult to analyze EEG data collected in mobile experiments. [1]

Many signal processing approaches have been proposed to remove motion artifact including artifact subspace reconstruction (ASR), dual-layer artifact removal, IMU-based artifact removal, impedance-based artifact removal, and many more. [2-4]. One common criticism of signal processing approaches to artifact removal is that there is no way to determine if the cleaning method removes or distorts the neural component of the signal. [3] Without a ground truth comparison, it is difficult to determine the efficacy of a noise removal technique.

EEG phantoms provide a solution to this problem. A phantom that can produce a scalp potential similar to that of human skin and a motion artifact similar to that of a human can serve as a test-bed for signal processing approaches to artifact removal. A motion platform can be used to take the head through realistic motions to induce artifact while a known signal is input. Different cleaning approaches can then be applied and the result compared to the original input data to determine the validity of the cleaning approach. For example, this phantom-motion-platform approach has been used to study the efficacy of Independent Component Analysis (ICA) for motion artifact removal with a dual-layer approach to data acquisition. [3] [5]

The validity of data obtained from any phantom depends on how well it replicates the properties of the system it models. In this study we evaluated two different phantom materials model the signal properties of the motion artifact in EEG. An ideal phantom will recreate both the amplitude and the step-to-step variability of human motion artifact. The objective of this study was to verify that phantom materials can replicate these properties.

To verify that a phantom can produce human-like motion artifacts, we compared human EEG data to phantom EEG data generated by repeating the human's motions. Ten study participants walked at five different speeds (1.00, 1.25, 1.50, 1.75, 2.00 m/s) on a force-plate instrumented split-belt treadmill (AMTI, Watertown, MA, United States) while motion capture cameras (Motion Analysis, Rohnert Park, CA, United States) recorded participant head position and orientation, and an EEG system (Biosemi, Amsterdam, Netherlands) recorded motion artifacts. Motion capture data was translated into Cartesian positions and rotations using Visual3D (C-Motion, Germantown,

MD, United States). Two phantom heads based on the Open EEG Phantom (https://osf.io/qrka2/) were created using i) 3 g/L Agarose and 0.1 g/L NaCl and ii) 20 wt% ballistic gelatin. The phantom was bolted to the platform of a six degrees of freedom motion platform (Quanser, Toronto, ON, Canada). The phantom was equipped with the same Biosemi system used in human testing. EEG data were recorded while the motion platform moved the head through the trajectory obtained from each human recording.

A band-pass filter of 1.2 to 50Hz was applied to all EEG data and bad channels were interpolated using EEGLAB [6]. Data was epoched between successive right heel strikes detected using the instrumented treadmill data. The power of the signal was computed over each epoch in the human and two phantom conditions. Mean power across epochs was computed to determine typical artifact amplitude and standard deviation across epochs was computed to determine inter-trial variability.

We performed two within-subject repeated measures 2-way ANOVA tests to determine the effect of walking speed and skin type (human, agarose, ballistics gelatin) on average artifact amplitude and artifact inter-trial variability. For average artifact amplitude, the main effects of speed and skin type, as well as the interaction of speed and skin type were all significant ($p<0.05$). Post hoc analysis showed that at every walking speed, agarose artifact amplitude was greater than human artifact amplitude, and both were greater than ballistics gel artifact amplitude. For inter-trial artifact variability, the main effects of speed and skin type, as well as the interaction of speed and skin type were all significant ($p<0.05$). Post hoc analysis showed that at every walking speed, agarose and human inter-trial variability was not significant, while both were significantly higher than ballistics gelatin ($p<0.05$).

These results represent an important step toward the design of an EEG phantom that accurately generates human-like motion artifact. Prior testing has shown that increasing agarose salt concentration decreases artifact amplitude, so future work must focus on tuning the electrochemical properties of the phantom material to more exactly match the artifact properties of human skin. Once the ideal match is made, we feel this will be a valuable tool for the community for assessing future systems.

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8 Mobile dry EEG evaluation of cognitive load during sitting, standing, and walking

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Cognitive load is highly cited as a hindrance to the walking ability of prosthesis wearers [1] and users of other assistive devices as shown through qualitative surveys in clinical literature. A quantitative measure of cognitive load could be useful to assess the ease and efficacy of a device, evaluate the ease of interaction with an adaptive shared control system, or use as a device-agnostic metric of comparison across different devices. However, it has been difficult to identify clinical and biomechanical metrics that measure cognitive load [2]. To address this need, this work leverages the brain's innate responses to stimuli to quantitatively evaluate and track changes in cognitive load.

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Event-related potentials (ERP) in electroencephalography (EEG) can be used to quantitatively measure cognitive load from cortical signals. Mobile EEG systems have been recently improved for use in natural environments as opposed to limited and controlled laboratory setups [3]. However, to our knowledge no studies have evaluated the impact of movement on ERP measurement during the three tasks of sitting, standing, and walking.

To better understand the impact of cognitive load during activities of daily living, we measured brain activity from EEG as participants attended to an auditory stimulus paradigm during sitting, standing, and walking. In considering patient comfort and clinical feasibility, this work uses a dry, wireless EEG system (DSI 7, Wearable Sensing) that can be quickly set up and thus may be used by clinicians in rehabilitation settings to quickly identify the best assistive device for a patient.

The stimulus paradigm used in this work consisted of an auditory oddball task with two types of stimuli (high-pitched target tones on 10% of trials and low-pitched non-target tones on 90% of trials). Participants were asked to report the number of target stimuli that were heard during each task. The P3 event-related potential, which is sensitive to cognitive load [4], was extracted from the EEG signals in each condition. EEG signals were filtered offline between 0.5 Hz to 30 Hz, and Infomax Independent Components Analysis was applied to identify and remove epochs with noise from the non-neural components using built-in functions from EEGLAB [5] and ERPLAB [6]. The remaining trials were averaged and the mean amplitude at the Pz electrode between 250-350 ms post stimulus onset was used as the P3 measure. A linear mixed-effects model was applied using sitting as the reference condition and subject as a random factor to account for inter-subject differences. To understand the impact of motion on cognitive load, we calculated the motion level on each trial from the rms of the head acceleration.

Results showed that P3 was significantly lower during walking compared to sitting ($p = .039$), indicating that cognitive load was higher during walking compared to the other activities. No significant differences in P3 were found between sitting and standing. Head motion did not have a significant impact on the measurement of cognitive load.

The stimulus paradigm we used can be applied at various times during walking and ambulatory activities relevant to lower limb prosthesis wearers and users of other assistive devices. Therefore, these results encourage the use of a dry EEG system to further investigate cognitive load during dynamic activities in individuals with and without motor impairments. A quantitative, objective metric of cognitive load such as ERP could inform the device design, clinician choice, and could be used to evaluate the safety and reliability of a wearable assistive device.

Future work will include quantifying cognitive load in lower limb amputee participants. By applying ERP stimuli during specific phases of gait, it may be possible to identify points in the gait cycle and movements that may require more cognitive control, or to identify movements of cognitive overload that may lead to falling in clinical populations in challenging or distracting environments. This platform could be used in life-like scenarios relevant to long term prosthesis use, and these improved metrics may allow us to target certain aspects of the device functionality to lessen the cognitive burden of walking. This could improve long-term prosthesis adoption and lead to increased mobility and quality of life for prosthesis-wearers.

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9 Individual Variability in Aesthetic Experience: A Mobile EEG and Eye Tracking Study at the San Diego Museum of Art

Hardware Posters

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How does visual attention relate to aesthetic experience? Do we explore and attend to art works differently when we find them arousing versus boring or cheerful versus unsettling? To address these questions, eye tracking and wireless electroencephalographic (EEG) data (28 channels) were recorded from healthy adults viewing diverse paintings displayed in the galleries of the San Diego Museum of Art. Afterwards, the same paintings were revisited, and a Likert scale was used to rate various aesthetic emotions elicited during the viewing phase by each one (e.g., fascination, calmness, indifference, surprise, amusement), allowing arousal and valence scores to be derived for each painting.

Preliminary results indicate two distinct patterns of aesthetic engagement. For some individuals – classified as strong responders – overall viewing times increased dramatically with arousal, whereas for others – labeled weak responders – viewing times increased with arousal to a much lesser extent. These two groups were differentiated along a number of other dimensions of gaze as well. Strong responders, for instance, tended to make longer fixations with smaller saccadic amplitudes than weak responders.

Fixations were also classified into two distinct viewing patterns -- ambient (characterized by a long preceding saccade) or focal (preceded by a short saccade). The ratio of ambient to focal fixations tended to be higher in weak responders than strong ones, suggesting that weak responders tended to rely more heavily on ambient gaze strategies, whereas strong responders tended to rely more heavily on focal ones. Finally, preliminary analysis of fixation-related potentials (FRPs) computed for ambient and focal fixations revealed that focal fixations elicited larger onset potentials (peaking between 50 and 100 ms) than ambient ones, particularly over right occipital channels – likely reflecting early attentional modulation of visual processes. Further, ambient fixations on high arousal paintings tended to elicit more positive FRPs than focal fixations from around 200 to 500 ms post-fixation, whereas this effect was not observed in the response to low arousal paintings. This outcome may reflect perceptual and semantic integration processes that are more heavily modulated when a viewer feels engaged versus disengaged by a painting.

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10 MindHive: A community science platform for human brain and behavior research

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Human brain and behavior research has traditionally, and paradoxically, taken place mostly in spaces that are shielded from humans' natural habitat: In a typical human neuroscience study, scientists recruit university students to participate in well-controlled laboratory studies, devoid from naturalistic behavior. This approach is currently under attack from multiple angles. First, researchers have questioned the extent to which laboratory paradigms constitute adequate models for real-world perception and (inter)action. Scholars have further raised alarm that the university laboratory model has resulted in systematic biases in the data that is collected. Relatedly, and as become painfully evident during the pandemic, there is widespread community distrust in science and scientists, which can have public health consequences.

While a growing number of researchers is turning to open, citizen science as a tool to both educate and involve the public in science inquiry, these initiatives continue to be most prevalent in the 'hard' sciences (e.g., ecology, astrology, neurobiology), and often seem to be aimed at enticing the public to help scientists collect data, rather than at including communities as partners in the scientific inquiry process itself.

MindHive, a browser-based community science platform for human brain and behavior research, seeks to foster a healthy science ecosystem by engaging users in the full range of scientific inquiry, that is, the making of science. MindHive is geared toward (a) students & teachers who seek authentic STEM research experiences, (b) cognitive and social scientists who seek to address their research questions outside of the lab, and (c) community-based organizations who seek to carry out grassroots research for policy change. Taking an open science approach, MindHive features a collaborative study design environment, comprising an experiment builder, a database of validated tasks and surveys, and a public-facing study page; a peer review center; and GDPR-compliant data collection, data management, and data visualization and interpretation functionality.

We describe case studies from the COVID-19 pandemic to illustrate opportunities and challenges associated with enabling scientists, students, educators, not-for-profit organizations, and community members to collectively contribute studies, resources, and research data to projects; with the goal to support STEM learning, scientific discovery, and public policy.

11 BIDS-Motion: organizing motion data for reproducible MoBI research

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With growing interest in open science, an increasing number of publishers and funding bodies encourage scientific data to be shared according to "FAIR" (Findability, Accessibility, Interoperability, and Reusability) principles for digital data management. The BIDS (Brain Imaging Data Structure) framework enhances interoperability and reusability in management and sharing of neuroimaging data by standardizing the file names, their organization over directories, and the description of experimental metadata. In the field of Mobile Brain-Body Imaging (MoBI), motion data are often recorded in conjunction with neuroimaging data such as electroencephalography (EEG) and functional near-infrared spectroscopy (fNIRS), for which a BIDS specification already exists (EEG) or will be released in the near future (fNIRS). The work presented here aims to extend the BIDS specification with motion data, defined as time series of positions, orientations, and their temporal derivatives, outlining how to organize and document the raw data and metadata. This is a crucial step towards improved interoperability and reusability of MoBI datasets and will thereby boost replicability and overall quality of MoBI research.

A wide variety of motion capture systems are used in MoBI research, resulting in different proprietary file formats. Researchers in individual labs are often restricted to the proprietary software that comes with the system, but it is also common for labs to develop and use in-house data conversion and analysis software. Without a standard file format, cross-laboratory data sharing will be more costly due to time and effort it takes to convert between

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multiple formats. Furthermore, without proper documentation, details that are necessary for meaningful interpretation of data may be missing, such as information about the spatial axes associated with recorded data. Another important aspect of a typical MoBI experiment is time synchronization within and between data modalities. Some motion tracking systems record latency information for each sample in the time series, while for other systems the effective sampling rate has to be inferred from the duration and number of samples in recorded data.

BIDS-Motion addresses the heterogeneity of experimental setups in MoBI is by specifying raw motion data to be converted and shared in ASCII format as tab-separated values (.tsv). The time series of object positions, orientations, accelerations, and/or their temporal derivatives are measured and expressed relative to a reference coordinate frame. To ensure unambiguous interpretation of the data, BIDS-Motion recommends the corresponding spatial axes to be described by a one-, two-, or three-dimensional coordinate system. Besides specifying an easily accessible file format, BIDS-Motion provides researchers with guidance on time-synchronization within the motion modality, accounting for the various types of timing information available from different motion recording systems, and for synchronization across recording modalities (for example, simultaneously recorded EEG and motion data). The BIDS-Motion extension to the BIDS standard is not limited to motion data in physical space but can also be used to represent simulated movement in virtual space.

BIDS-Motion provides solutions to common obstacles to data sharing in MoBI, most of which are consequences of the inherently multimodal nature of MoBI setups. Next to neuroimaging data, motion is the most integral and commonly included modality in MoBI studies. By placing motion data in the BIDS framework, BIDS-Motion tightens the link between brain and body research and facilitates interdisciplinary collaborations by making data sharing easier. With enough interest from the MoBI community, BIDS-Motion will ultimately contribute to enhancing reproducibility of MoBI research as a building block of good scientific practice.

12 Time to re-calibrate: An alternative approach for selecting calibration data for ASR

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Artifact subspace reconstruction (ASR) is a denoising solution for continuous EEG data that is especially advantageous for MoBI experiments with large movement artifacts. Since its release (Kothe and Makeig, 2013), multiple studies have searched for parameters yielding the best denoising performance (Chang et al., 2020). The performance of the current implementation depends on the quality of artifact-free calibration data. In many MoBI studies, data may have such frequent high-amplitude artifacts that the default ASR search for calibration data fails or calibration includes artifacts. We propose here a modification to improve the robustness of ASR in such cases. We propose to use single data points instead of sliding windows for the maximum flexibility in calibration data selection. The principle is very simple: if we use a sliding window, even if only few data frames are bad, the entire window might become unusable. However, if we treat each data points independently for the selection process, we can maximize the amount of artifact-free calibration data. This approach takes advantage of the fact that the subsequent principal component analysis (PCA) does not require preservation of data time-series dynamics and thus does not require contiguous datapoints. For selecting clean data points for calibration, we implemented two approaches for comparison: The first approach sorts amplitude at each timepoint followed by differentiation and k-means clustering to find the data point clusters that have smallest variances across electrodes and largest data length in samples (k-means method); The other approach calculates maximum values across electrodes at each time point and fits a generalized extreme value (GEV) distribution to find a mode, data below which are defined as clean data (GEV method). We compared the proposed k-means and GEV methods with the default sliding window method on EEG datasets (n=13) recorded during three-ball juggling, a novel MoBI paradigm of Swartz Center, which is contaminated by intensive upper body movement at > 1-2 Hz and is thus a challenging test case. Both proposed methods found 10-20% of data usable for calibration, while the default approach found only about 1% of usable calibration data. The automated window rejection at the end of the clean_rawdata(), with channel number tolerance 0.02 and ASR threshold SD = 5, rejected 30.1% (SD 19.0), 25.1% (SD 16.8), and 16.4% (SD 11.7) of data processed with the default, k-means, and GEV methods, respectively. Pairwise t-tests between default vs. GEV and k-means vs. GEV reached statistical significance (all $p<0.025$, Bonferroni correction), which confirmed that the proposed methods clean the data more effectively. We also found the possible reason why abnormally high cutoff values for the ASR, such as 10 to 20 SD, have been recommended in the default methods: the proposed method normalizes the conventionally inflated SD cutoff values into more intuitive values in terms of normal distribution. We conclude that the proposed modification on ASR provides a solution to more robustly find usable calibration data for ASR. Our methodological improvement extends the possibility of MoBI to enable to study novel types of motor tasks which were difficult using conventional methods.

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13 Comparison of EEG source localization estimations using simplified and anatomically accurate head models in young and older adults

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There is a need to investigate the reliability of head models for source localization in high-density electroencephalography (EEG) research on older human participants. Generic head models are typically based on magnetic resonance images from healthy young participants. Age-related changes in brain structure, such as cortical atrophy, are not reflected in current generic head models and may influence electrical properties in older subjects compared to younger subjects. Directly comparing different head models in both younger and older adults would provide a quantitative assessment of potential differences in source localization between the two groups. In particular, it would provide a means to assess source localization discrepancies introduced by using generic head models, inexact electrode locations, and inaccurate brain region segmentation.

We compared EEG source localization results using four different head models of varying levels of complexity on EEG data from younger and older subjects. The models we compared were: 1) generic three-layer boundary element method models based on the Montreal Neurological Institute generic head images and standard 10-5 system with 120 electrodes; 2) generic three-layer boundary element method models with digitized 120 electrode positions warped to the head model; 3) subject-specific five-layer finite element method model using a simplified segmentation that assumed constant skull thickness and digitized electrode positions warped to the head model; and 4) subject-specific five-layer finite element method model with anatomically plausible segmentation and digitized electrode positions warped to the head model. We calculated localization differences as the Euclidean distances between source reconstruction locations from models 1-3 and those estimated by the finite element method anatomically plausible head model (model 4). We hypothesized that simpler head models (models 1-3) would have greater source localization differences relative to the most complex model (model 4). Additionally, we hypothesized that the source localization differences relative to model 4 would be larger for older adults than those estimated for young participants.

We analyzed EEG data from ten healthy young (20-40 yrs old) and seven high functioning healthy older participants (>70 yrs old) who completed a series of actual walking and imagined walking tasks following a previously published protocol (Clark et al. 2020). After EEG preprocessing, we used independent component analysis for blind source separation. T1-weighted magnetic resonance imaging provided data for subject-specific head model construction. We digitized the electrode locations for each participant using an infrared 3D scanner and used FieldTrip and SimBio toolbox to construct finite element method head models. The simplified segmentation with constant skull thickness was estimated following the default FieldTrip-SimBio pipeline to segment the T1 image into scalp, skull, cerebral spinal fluid, gray matter, and white matter (Vorwerk et al. 2018). To achieve a more anatomical realistic model, we used the spm12 cat12 toolbox and then incorporated the brain segmentations into the FieldTrip forward head model pipeline. The generic three-layer boundary element method model including the scalp, skull, and brain compartments was available in EEGLAB. We applied dipole fitting to perform source localization. We retained the brain components based on the results from ICLabel, residual variance from dipole fitting, and visual inspection. Lastly, we warped all source reconstruction locations to the Montreal Neurological Institute space for all head models to allow for the comparison of source locations across

generic head models and subject-specific models. We compared localization differences across models and between young and older populations using the Welch two-sample t-test. Significance was set at $\alpha=0.05$.

Results indicated that simpler head models had greater localization differences compared to the reference model 4. There were similar residual variances for dipole fitting across all models. Residual variances for brain components from models 1-3 were highly correlated with the residual variances from model 4 across all participants (median $r>0.94$). The localization differences for dipoles across participants were 19.9±6.5 mm, 13.5±3.5 mm, and 7.4±1.9 mm for models 1-3, respectively, when compared to model 4 (all $p<0.05$). The localization difference relative to model 4 was also higher using the generic boundary element method model with generic electrode locations (model 1) compared to the same model but with digitized electrode locations (model 2; $p=0.001$). The localization difference in older adults was slightly higher than young adults (15.6 mm v. 12 mm) only when comparing model 2 with model 4 ($p = 0.03$). Future analyses should compare localization differences between young adults and low-functioning older adults who have substantial brain structural changes to further examine the effects of aging on source localization differences using a generic head model.

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14 Subject misrepresentation in EEG research for mobile brain/body imaging

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Motivation. Mobile brain-imaging using electroencephalography (EEG) allows researchers to understand neural control of movement especially during walking, running, and other locomotor tasks such as cycling and recumbent stepping. EEG researchers may have encountered difficulty when setting up EEG with different hair types, primarily curly, tightly coiled, textured, and voluminous hair. The largest portion of the global population with these hair types identifies as African, African American, or Caribbean [1]. If different hair types influence EEG preparation and setup, then they are at risk of being neglected in recruitment practices, declined from participating, or excluded from datasets. Initiatives to design compatible hardware are gaining attention but are limited primarily to the Sevo electrode group's designs that improve electrode contact with the scalp for data collection [2].

Is there a systemic exclusion of subjects in MoBI research and if so, how can we, the EEG community, address it? As a starting point, we created and shared a working document with EEG researchers to provide options for preparing different hair types for recordings (UCF BRaIN Lab EEG Hair Project, https://hellobrainlab.com/research/eeg-hair-project/). We also wanted to survey other researchers to determine whether this is a community-wide issue, and report what the potential sources of exclusion problem are. Here, we present preliminary results from our survey for current or new researchers using EEG in MoBI studies.

Methodology. We made an online Qualtrics survey for EEG researchers and participants available on the UCF BRaIN Lab's website and distributed it through our professional networks, social media, and during events hosted by organizations like Black In Neuro. The online survey was approved by the Institutional Review Board at the University of Central Florida. From August to December 2021, 230 total responses were collected from EEG researchers in research and clinic, as well as from participants. The results discussed herein focus on respondents who identified as EEG researchers and responded to questions related to EEG preparation, EEG hardware, subject recruitment, and subject exclusion. We performed statistical analyses in Qualtrics.

Results. EEG researchers most frequently used the words research, participant, people, community, and time when asked to identify barriers in EEG research that would prevent equitable recruitment and retention.

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We wanted to quantify possible sources of the barriers mentioned in survey responses but first wanted to determine how many of the participants recruited in EEG studies identify as Black/African American. Table 1 reports the numbers in each category that indicate respondents that recruited any number of Black/African American participants had also excluded participants on the basis of hair. This suggests that there might be a relationship between Black/African American participants and the subjects who are declined or excluded from participating in brain research.

Table 1: Total number of EEG preparations relative to the total number of Black/African American participants recruited to participate.

	Black/African American participants recruited							
	< 5	6-10	11-20	21-50	> 50	Unknown	Prefer not to answer	Total
Total EEG collections								
< 10	11	0	0	0	0	2	1	14
11-25	11	4	0	0	0	1	0	16
26-50	16	5	1	1	0	2	0	25
51-100	19	4	4	5	0	1	0	33
101-200	14	6	2	6	1	3	0	32
200+	7	2	7	9	12	5	0	42
Total	78	21	14	21	13	14	1	162

A ranked correlation analysis (p=0.0005) revealed a direct correlation between the total number of EEG preparations and potential for misrepresentation or disproportionate exclusion. Results suggest that race, ethnicity, and hair play a crucial role in the recruitment and retention of Black/African American participants in EEG studies.

Of the Black/African American subjects recruited, we wanted to give examine the extent of how hair type may lead to the exclusion of subjects in this demographic. Table 2 reveals the consistent exclusion of subjects due to hair type, which might ultimately lead to the exclusion of racial and ethnic groups.

Table 2: Total number of Black/African American subjects recruited compared to the total number of subjects excluded from brain research due to hair type (curly, coily, voluminous, textured).

	Black/African American participants recruited							
	< 5	6-10	11-20	21-50	> 50	Unknown	Prefer not to answer	Total
Total subjects excluded due to hair type								
< 5	66	0	0	0	0	48	0	114
6-10	6	2	0	0	0	1	0	9
11-20	1	2	3	0	0	3	0	9
21-50	0	0	2	0	0	2	0	4
> 50	0	0	0	1	2	1	0	4
Unknown	5	2	2	3	2	7	0	21
Prefer not	0	0	0	0	0	0	1	1
Total	78	6	7	4	4	62	1	162

A one-way ANOVA revealed a strong statistical relationship (p=0.001) between the total number of recruited Black/African American subjects and the number of those subjects declined or excluded from the study.

Implications. These findings emphasize that the MoBI community and EEG researchers must consider how their current recruitment and retention processes are impacted by hair types that are often linked with race or ethnic origins. Thus, hair type as a criterion for exclusion of participants can lead to unintended exclusion of racial or ethnic communities in EEG findings.

Acknowledgments

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15 Characterizing EEG Artifacts during Real World Table Tennis

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Motivation. Ecological valid, real-world conditions are necessary to study neural correlates of natural cognition [1]–[5]. Maintaining high-fidelity signals in mobile conditions is challenging due to physiological and non-physiological artifacts. Some approaches to reduce artifacts use reference noise signals, such as separate electro-oculogram (EOG) channels, neck electromyography (EMG) channels, or head movement measured with inertial measurement units (IMU), to aid in signal processing [6]–[11]. In the dual-layer approach to EEG, noise channels provide an alternative representation of motion artifact than head acceleration or rotation [12]–[15]. Noise channels are electrically isolated and mechanically coupled to scalp channels, which may include more of the cable-induced artifact than other reference noise signal sensors.

Many mobile EEG studies that characterize noise use gait-related experimental paradigms (i.e., walking or running) [11], [16], [17], while fewer studies characterize noise in non-gait-related tasks. Table tennis may be a useful sport to investigate visuomotor feedback, anticipation, object interception. Players use their whole bodies to move and hit the ball, and their rotational movements may induce different artifacts than locomotion. An understanding and characterization of the artifacts in mobile EEG recorded during table tennis could improve our confidence in future interpretations of neural data for many types of non-gait-related human movement.

Methods. We collected and analyzed data from 20 participants with a wide range of athletic experience. Participants wore a high-density dual-electrode EEG cap made up of 120 scalp electrodes and 120 noise electrodes. Eight of the original 128 scalp electrodes were re-purposed to measure neck muscle activity. We placed inertial measurement units on a table tennis table, net, ball machine, and on the handles of two wooden paddles to mark event timing. For the last four participants, we placed an inertial measurement on the participant's forehead to measure head movement. Participants played table tennis with a ball machine and human player, broken into four 15-minute blocks. Trials involved cooperative or competitive play with a human player, or stationary or moving hitting with the ball machine.

The data processing pipeline was similar to past studies from our lab. Data were merged, 1-Hz high-pass filtered, and segmented into trials. We rejected, spherically interpolated bad channels, and averaged referenced the scalp and noise electrodes separately. Next, we epoched data -1 to 3.5 seconds around the time when the ball was presented to the participant (either as a feed from the ball machine or a hit from the human player). To determine time-frequency characteristics of each reference signal in measuring noise (noise channels, head IMU, and EMG channels), we created event-related spectral perturbation plots (ERSPs). We compared these to ERSP plots of individual scalp channels for each table tennis condition. The ERSP plots were time-warped to the average latency of hit and feed events across epochs and per condition. The spectral baseline for each ERSP plot was the average log spectrum from all time points in that condition. We used bootstrap statistics to find significance differences from baseline (alpha 0.05) as a grand average ERSP plot across participants, and as individual ERSP plots to investigate the noise both across and within participants, similar to Kline et al. [17].

Results. As expected, the scalp channels at the back of the head had similar time-frequency characteristics as the neck muscle channels, which appeared as a broadband increase in spectral power preceding participant ball strike. Noise channels across participants and table tennis conditions had spectral power increases in low frequencies around participant ball strike. The magnitude of spectral power fluctuations in the moving condition were higher than the stationary condition, especially for neck muscle channels. Some of the scalp and noise-matched channels had similar spectral power increases in the low frequencies around ball strike, but this pattern was not consistent across participants and only relatively consistent across electrodes.

Implications. Reference noise signals are useful in characterizing artifact in mobile EEG data. Our results show that different reference noise measurements can vary considerably, providing unique information to aid in cleaning EEG scalp channels that are used to derive brain components.

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16 Cortical Classification of Mobile EEG with Graph Neural Networks

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Robust classification of mobile EEG during demanding physical tasks is a critical component when establishing BCI for settings outside of the laboratory environment. Traditional architectures, such as EEGNet, do not consider the interaction between brain signals of multiple, discrete brain regions [2, 3]. Incorporating the interconnectivity between brain regions may improve the ability to classify neural states related to performance. In this study, we employ a graph convolutional network (GCN) to take advantage of the neural interconnectivity. In particular, we will be using GCNs-Net, a GCN adapted for EEG signals by Hou et al [2]. We classified P300 signals in EEG data collected from 13 subjects performing an oddball detection task during locomotion [1] and compare our results with a traditional architecture, EEGNet. Using the data from Bradford et al [1], we achieved an average of 90% accuracy on within-subject tests and 72% accuracy on cross-subjects tests. This was comparable to prior results on the same data [4]. This work shows that GCNs can be valuable tools in mobile EEG classification.

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17 Motor Attempt or Motor Imagery? The Effect of Brain-State on Functional Outcomes of Brain Computer Interface (BCI)-Mediated Neurofeedback Training for Stroke: A Scoping Review.

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Introduction. Rehabilitative brain-computer interface (BCI)-based neurofeedback training (BCI-NFT) is a promising neurorehabilitation strategy for improving motor function. To enhance motor capabilities, BCI-NFT aims to link brain activity to strengthen adaptive neural connections. To create this link, a brain-state, i.e., brain activity during motor imagery (MI) or motor attempt (MA), is used to control an external device, typically functional electrical stimulation or robotic devices, and thereby, provides enhanced sensory stimuli to the central nervous system.

Individuals with limited or no motor control can still imagine or attempt to move, and the associated brain activity can be extracted and used as the control command for BCI systems [1, 2]. Thus, unlike conventional physical therapy, BCI-NFT does not require residual motor control, and therefore, it may be particularly advantageous for individuals with non-progressive neurological disorders with limited or no residual motor control in the target limb.

Brain activity during MI continues to be the most commonly utilized brain-state for the control of BCI-NFT systems [3]. However, with MI, patients may have to actively suppress the movement of the target limb while imagining the movement, which often requires learning and prolonged concentration and might be difficult for very young or cognitively challenged individuals [4]. Additionally, it is clearly more natural to attempt the movement, as well as more verifiable [5]. When the goal of the BCI-NFT is strengthening or establishing motor function, controlling the BCI system by attempting to move may further improve outcomes because it maximizes the similarities between the brain-state used to control the BCI and the functional task [6]. Here we investigated the effect of MI and MA on functional outcomes of BCI-NFT as measured by Fugl-Meyer Assessment (FMA); FMA is the most commonly reported measure in BCI-NFT studies [7]. A systematic review by Bai et al. concluded that MA conferred greater functional benefit; however, this was based on only 2 MA-based and 7 MI-based randomized clinical trials (RCTs)

[8]. Here our search included all studies with Sackett level of evidence III and IV [9] as well as RCTs (level I and II). We hypothesized that MA would result in greater FMA improvements due to the fact that it is more natural and therefore easier to preform and more similar to the target motor task (i.e. more task specific).

Methods. We performed a scoping review to identify all studies (Level of evidence I-V) on BCI or neurofeedback paradigms using mobile brain imaging technologies with the aim of improving motor function in persons with non-progressive neurological disorders. A title and abstract keyword search was conducted utilizing the following search terms and adapted as needed for the PubMed, Web of Science, and Scopus databases: “motor” AND “Brain Computer Interface” OR “BCI” OR Neurofeedback” OR “BMI” OR “EEG biofeedback”. All papers that met our inclusion and exclusion criteria were divided into two groups: MI and MA. We have since performed an in-depth analysis of all MA studies (See abstract by Damiano et al), including a meta-analysis of the FMA scores. Here we are comparing FMA outcomes from all MA studies, with the exception of those in level V, with those from all Level I-IV MI studies. Only patients with stroke and only applications utilizing EEG for the BCI-NFT were included because these comprise the vast majority of studies in the literature. FMA scores were compared across groups using independent t-tests ($p<0.05$).

Results. A total of 138 BCI-NFT studies met our criteria,; of which 35 studies reported FMA score and were included in this comparison, 9 MA-based and 26 MI-based. Three studies reported median FMA changes instead of mean. Mean FMA changes ranged from 3.2 to 25.21 (6.65 ± 5.15, mean ±Std) for MI group and from 0.11 to 11.8 (5.27 ± 3.7) for MA group, with no significant between group differences ($p=0.428$).

Implications. Although MA was the superior brain-state when compared to MI in a sub-group analysis of Bai et al.’s systematic review [8], here the mean FMA change was slightly, but not significantly, higher for the MI group. Notably, the minimal clinically important difference in the FMA is reported as 5.5 points, which was achieved in the MI group and nearly so in the MA group, reinforcing the clinical potential of these paradigms for motor rehabilitation. While no recommendations can be made on which method produces superior outcomes, paradigms that utilize MA can be more easily implemented and therefore may be preferable for pediatric neurorehabilitation and for others who may not be as capable of producing reliable brain activation signals using MI.

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18 Developing a Mobile Brain-Controlled Exoskeleton for Enhancing Post-Stroke Rehabilitation

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Strokes are widespread in the middle-aged and elderly populations around the world, causing not only high medical expenses, but also severely depriving patients of the ability to care for themselves and require long-term rehabilitation to retrain their behavior. In the past, traditional rehabilitation relied on training and performance assessment by physical therapists, which has been in place for many years, but lacked accurate performance indicators and targeted medication at the true source - the brain. Therefore, we developed a brain-machine interface exoskeleton robot for rehabilitation of stroke patients, using electroencephalography (EEG) as a method to measure the degree of activation of the patient's brain during movement and Movement-Related Cortical Potential (MRCP) as an indicator. Patients will wear an EEG headset with the exoskeleton robot and will be asked to walk autonomously, which is termed as active rehabilitation. Although the patient will not be able to walk autonomously as a normal person, he/she can be assisted by the brain-machine interface and the exoskeleton robot, and when the brain activation indicator level reaches a certain threshold, the exoskeleton robot will be used to control assisted walking, which is termed as passive rehabilitation. The system uses a wireless Artise 32ch EEG headset to measure the EEG signals in real time, while the computer will receive the EEG streaming signals using the Lab Streaming Layer (LSL) transmission standard. After sequentially going through several pre-processing steps, the computer will calculate the Time - Frequency Analysis results in real time. Based on this result, the system will decide whether to transmit commands to the exoskeleton robot to assist in the path of travel. The computer is connected to the exoskeleton robot through serial ports and Bluetooth as the transmission standard.

19 Determining Optimal Mobile Neurofeedback Methods for Motor Neurorehabilitation in Children and Adults with Non-progressive Neurological Disorders: A Scoping Review

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Introduction: Neurofeedback is a promising neurorehabilitation strategy emerging from the Brain Computer Interface (BCI) field. In contrast to bypassing voluntary motor control by linking the brain to a wearable device, neurofeedback harnesses and links event-related brain activity during real or imagined movement to strengthen neural connections and thereby enhance function. Data from individual studies and systematic reviews in neurorehabilitation populations (predominantly stroke) generally indicate that BCI-neurofeedback paradigms demonstrate positive functional outcomes from relatively short training durations; however, outcomes and methodologies vary across studies. We chose here to conduct a scoping review of all clinical studies deploying neurofeedback training in patients with non-progressive neurological disorders who attempted to perform (rather than imagine) a specific motor task while receiving external feedback linked to their brain activity. Our primary focus was to highlight the methodological similarities and differences across studies and to relate specific approaches to variations in functional outcomes so as to provide recommendations to guide future development and clinical implementation of these systems to improve motor functioning.

Patients and Methods: We performed a scoping review (PRISMA-ScR Checklist) of PubMed, Scopus and Web of Science databases to identify all neurofeedback studies aiming to improve motor function in non-progressive neurological disorders by linking brain activation during attempted movement to training with additional sensory input (e.g. FES). Review of title and abstracts, full texts and data extraction were all done independently by at least two authors, with disagreements resolved by discussion. Only studies which involved active movement or an attempt to move were included, excluding those using motor imagery alone. We further limited studies to those including motor outcomes and those using mobile brain imaging (e.g. EEG, NIRs). The most commonly reported functional measure will be used to statistically evaluate (compare or correlate) outcomes from different methodological features across studies ($p<0.05$).

Results: From 5,189 identified studies, 23 studies met inclusion criteria, all but one (incomplete SCI) in patients with stroke. Thirteen studies reported FMA changes after intervention and six reported ARAT changes with mean changes of 6.57±4.43 and 8.34±9.0, respectively. Only four studies reported FMA differences between experimental and control groups, 4.07±0.57, (none for ARAT). Independent t-tests assessed the effect of feedback type (robotic: n=3, and FES: n=9) and co-interventions (yes or no) on FMA differences. Despite higher mean FMA values for FES feedback (7.5 ±1.6 vs 5.4 ±4.42; p=0.49), outcomes were not significantly better. Conversely, the ARAT mean difference was higher for robotic (n=3) vs. FES feedback (n=3) (11.59 ±10.53 vs 5.10 ±7.34), also not significant. The inclusion of co-interventions showed no consistent or statistically significant effect on FMA and ARAT scores (For FMA: none=6.45 ± 5.28 [n=9], yes= 6.83 ± 2.04 [n=4]; p = 0.89, For ARAT: none=5.16±6.32 [n=4], yes=14.71±12.79 [n=2]; p=0.47). Mean FMA change also did not differ by the level of evidence (II=6.94±2.63, III= 3.74±4.19, IV=4.78±4.62, V=9.50 ±5.10; p = 0.38). A dose response was shown by a moderate positive Pearson correlation between FMA improvement and number of sessions (r = 0.67, p = 0.012). Despite similar correlation values between ARAT score and number of sessions; the correlation was not statistically significant (r = 0.70, p = 0.20).

The most consistent and arguably most effective paradigm that emerged was precise real-time detection and utilization of brain activation during motor onset to control external sensorimotor feedback. EEG with exceptional temporal resolution was the only modality utilized in all studies. FES and robotic devices were the most common feedback types. Several innovative highly technical BCI-based methods were explored across studies to maximize the reliability and accuracy of detecting brain activation. Given that timing of the sensory feedback with movement onset is presumed to be a critical factor in promoting neuroplasticity, the use of movement-related cortical potentials (MRCP) appear to be optimal since components such as peak negativity can be detected @500ms prior to movement execution.

Conclusions: Given the promising clinical potential of BCI-neurofeedback for motor rehabilitation even with short training durations, further development of these systems for broader clinical use is warranted. We further recommend greater utilization of these paradigms in pediatric neurorehabilitation where the potential for neuroplasticity is even greater than in adults. BCI-neurofeedback is essentially a form of self-neuromodulation during task specific active motor training with enhanced and precisely timed sensory feedback, all components of effective neurorehabilitation strategies.

20 Investigation of Independent Component Analysis for use in Brain-Computer Interface Neurofeedback Paradigms for Motor Rehabilitation

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Introduction: EEG-based brain-computer interfaces (BCIs) are increasingly being used in rehabilitation for people with neuromotor disorders. The underlying physiological principal is that the neuroplasticity of the central and peripheral nervous systems can be enhanced by detecting movement intent and providing afferent feedback [1]. The assumption is that this strengthened neural connectivity leads to greater changes in motor function. These BCI-neurofeedback paradigms often link a feature of the brain signal activated by motor intention or attempt with an assistive robotic device, electrical stimulation, or virtual movement, all of which rely on the accurate and well-timed detection of associated cortical processes [2-4]. One type of cortical signal from the sensorimotor region commonly used as control inputs are movement-related cortical potentials (MRCPs). These have been linked to the neurophysiological mechanisms associated with movement planning and execution and can be extracted from EEG data by averaging across trials [5]. The peak negativity (PN) of the MRCP is often selected as a control input because it occurs up to 500 ms before motor execution [6, 7], which enables contingent feedback to be delivered during movement execution. Several signal processing techniques have been used to reveal MRCP on an individual trial level, often including spatial filters or source imaging [6, 8]. Surface Laplacian filters are spatial filters that produce more pronounced topographies than channel-level signals [6]. However, these do not give information on where in the brain the signal originates. Independent component analysis (ICA) combines the benefit of spatial filtering and source imaging by calculating maximally independent cortical processes with fixed scalp topographies to identify stable cortical sources [9]. The purpose here was to compare the prominence and timing of PN during ankle dorsiflexor movement for three processing methods: no spatial filtering or source imaging, Laplacian filtering, and ICA.

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Methods: Nine healthy subjects (4 male, 5 female; age: 26.2 ± 7.0 years; 8 right handed, 1 ambidextrous) with no known neurological disease participated in this IRB-approved study. Data were collected using 64 EEG channels (Brain Products, Morrisville, NC) positioned according to the 10-20 international system (Easy Cap, Germany) with FCz as the reference. All performed an event-related paradigm with 60 repetitions of right ankle dorsiflexion while seated in a recumbent position. Trials consisted of a 2-second rest, followed by a cue to begin movement, then 3-seconds of dorsiflexion. For all three processing methods, EEG data were preprocessed using EEGLAB functions, as previously described [10]. This included elimination of noisy time periods and channels, high pass filtering at 0.5 Hz to remove line drift, common average referencing, and artifact subspace reconstruction (ASR) to remove high amplitude and high variance artifacts. Channel C1 was used for PN calculation for the channel and Laplacian methods because of its location on the sensorimotor region contralateral to the movement, just left of brain midline. The surface Laplacian was calculated on all nonremoved channels using the current source density toolbox [11]. ICA was computed using our previously developed offline processing pipeline [10]. One IC was selected per subject based on topography (near C1), ERD power in the mu and beta bands, and prominence of an event-related potential (ERP). ERP and PN were extracted for each trial for one channel, Laplacian, and IC signal by low pass filtering at 10 Hz for epochs 0.5 seconds before and after movement. For each method (channel, Laplacian and IC), trials were was normalized by their baseline standard deviation and then PN peak prominence (distance below the noise) was computed as the normalized PN magnitude. Kruskal-Wallis one-way ANOVA and a multiple comparisons test were used to assess differences in PN timing and magnitude across the methods.

Results: There was no statistically significant difference in PN timing between channel (Median: 1.00 ms, IQR: 438 ms), Laplacian (Median: 34.0 ms, IQR: 458 ms), and ICA (Median: 19.0 ms, IQR: 444 ms) methods (positive times are after movement onset; IQR = interquartile range). For PN magnitude, ICA had significantly more prominent peaks than channel (p = 0.0016) and Laplacian (p = 0.0024) methods (channel- Median: -2.521, IQR: 1.495; Laplacian- Median: -2.588, IQR: 1.464; ICA- Median: -2.762, IQR: 1.471).

Implications: ICA may be advantageous for BCI applications because the PN is stronger and more consistent than in channel-based and Laplacian methods, making it easier to detect during online processing. This advantage is likely even greater in patient populations, such as stroke or cerebral palsy, because ICA localizes task related cortical signals, which may not be as somatotopically organized or focal as in a non-injured brain.

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21 Comfort Panels: Personal Kinetic Panel Control with Neural Feedback for Increased Productivity and Decreased Stress

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1 Introduction

1.1 Effects of Natural Environment on Work Productivity

The natural environment can have positive effects on work productivity. Exposure to nature can improve attention (Berman et al., 2008), while bird songs and calls are associated with perceived stress recovery and attention restoration (Ratcliffe et al., 2013). The direct and positive effect of the natural environment on well-being, and possibly attention was also suggested by a systematic review of 25 studies (Bowler et al., 2010).

1.2 EEG Measures of Attention

Attention has been studied through EEG since the last century. Alpha band, especially lower-1 Alpha was suggested to be a good indicator of attention (Klimesch et al., 1998), while Theta band might be related to sustained attention (Busch & VanRullen, 2010). The role of the prefrontal area in the process has also been stressed (Sauseng et al., 2005).

1.3 Kinetic Panel Design

Kinetic Façades are façades with the ability to respond and adapt to the changes of the environmental conditions and can be found manifested in folding, sliding, expanding, shrinking, and transforming (Fox & Yeh, 2000). They have the potential to create environmentally safe, organized, enjoyable, and adaptable environments.

1.4 Summary

Exposure to nature can result in perceived attention restoration and increased attention which can be recognized with commercial EEG devices with acceptable accuracy and can be manipulated by controlling kinetic panels in modern buildings. In this paper, we will propose Comfort Panels featuring personalized kinetic panel control based on users' attention level, followed by a preliminary user study.

2 Design and Fabrication

2.1 EEG Measure

The EMOTIV EPOC 14-channel wearable EEG device was used in this study to monitor the brain activity of our users. We used Focus and Relaxation metrics from the official EMOTIV App, they were validated and have accuracy levels around 60% (Maskeliunas et al., 2016) which are sufficient for this study.

2.2 Installation Design

Plywood boards were laser-cut and assembled to create a frame with two rotatable panels attached, simulating kinetic facade systems of modern buildings. The design allowed us to attach motors to the panels to control the connectedness of interior and natural spaces by closing and opening them based on the users' focus level.

2.3 Interaction Design

We used Node-red, a graphic programming platform for JavaScript running on Node.js to design and program interactions for the project. The focus and relaxation metrics from EMOTIVE App were used to determine the state of our installation panels: the panels will be open when users start to lose their attention, introducing exposure to nature as a restorative intervention and will be closed after 5-minute intervention session to avoid unnecessary disturbance and annoyance.

3 Evaluation

3.1 Preliminary Study

We conducted a preliminary study with two participants to better understand the effects of our intervention. We used a video clip to simulate exposure to nature, and recorded focus and relaxation metrics from EMOTIVE App. Participants were asked to finished GRE math questions under different conditions: the participant in experiment group received 5-min intervention (video) when focus level fell below 30, while the control group received the same 5-min intervention 25 minutes after the start of the experiment according to Pomodoro Technique (Cirillo Consulting GmbH, 2019), a popular technique to increase work productivity.

3.2 Results

We recorded the focus and relaxation metrics of participants before, during, and after the intervention. Improvements were observed after introducing the intervention only for the experimental group. For the control group, a minor increase in Focus was also observed, but not as clear as the experimental group.

Interestingly, the two groups seem to have different "attention patterns" over time: periodic peaks can be seen in the results of the experimental group, while the control group seems to be able to maintain mid-high attention level during the whole session, suggesting potentially different attention strategies.

4 Conclusion

In this paper, we introduced Comfort Panels, an EEG-based neurofeedback kinetic facade design to increase productivity and possibly satisfaction by introducing exposure to nature as an intervention, followed by a preliminary user study to prove its' effectiveness. This study found that Comfort Panels can increase the focus level and could potentially be better than fixed-time break practices. The design can be extended to general space design where personal controls are included and can be integrated with existing non-intrusive sensors to eliminate the need for long-term use of EEG devices, making it more accessible and approachable.

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22 Body weight support differentially affects gait-related cortical activity during treadmill walking in children with and without unilateral cerebral palsy

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Motivation. Despite reports of some individual improvements, randomized trials of treadmill based gait training with body weight support or robotic assistance have not shown superior outcomes to traditional physical therapy in children with CP [1]. One reason these training paradigms may fail is their rote nature given that active participation and voluntary drive is critical for plasticity mediated motor learning [2]. Mobile brain-body imaging (MOBI) therefore represents a potentially powerful tool for rehabilitation because it enables quantification of an individual's gait-related cortical activity during prescribed bouts of gait training. MOBI paradigms in healthy adults, in particular those deploying electroencephalography (EEG), have implicated cortical involvement in multiple aspects of walking, including sustained activation of motor and parietal areas indicated by mu and beta desynchronization [3,4], coupling of spectral fluctuations to gait cycle phase [5], increased activation during more challenging walking tasks [6,7], and the role of beta and low gamma rhythms in adaptation of gait speed [6] and step length [8]. We recently reported the use of MOBI techniques to examine gait-related cortical activity in children with and without CP [9]. The purpose of this study was to use EEG evaluate differences in brain activity between standing rest and treadmill walking with and without body weight support in children with unilateral CP and age-matched typically developing controls.

Methods. Eight children with unilateral CP (GMFCS I (5) / II (3); age: 16.3 ± 2.8 years) and 11 age-matched children with typical development (TD; age: 15.0 ± 3.0 years) participated in this IRB-approved study after informed consent. 64-channel wireless active EEG (Brain Products, 1000 Hz) placed according to the 10-20 system and synchronized with motion capture (Vicon, 100 Hz) was recorded during standing rest (~2 min) and treadmill walking at self-selected speed with (BWS) and without (noBWS) 20% body weight support (~5 min each). EEG and kinematic data were processed using a similar pipeline adapted from EEGLAB functions as previously reported [6,9]. Briefly, after initial elimination of noisy time periods and channels EEG data was band pass filtered from 1-50 Hz, common average referenced and artifact subspace reconstruction (ASR) was applied to remove high amplitude and high variance artifact prior to independent component analysis (ICA) and subsequent dipole fitting (DIPFIT). ICs constituting electrocortical activity were identified based on examination of power spectrum, dipole location and residual variance and topographical sparseness. The remaining ICs were clustered across all subjects (TD and CP) using k-means based on power spectra, scalp topography and dipole location. Each identified cluster was split into two groups: CP and TD. Activation of each cluster during standing, BWS, and noBWS conditions was examined using time frequency analysis. Group differences in mu and beta band activation were evaluated using paired (within-group) and independent (between-group) t-tests with significance set at $p < 0.05$.

Results. Seven clusters of ICs were identified as having components from a majority of the participants with dipole locations centered in the prefrontal cortex, anterior cingulate, left, midline and right sensorimotor cortex, and left and right posterior parietal cortex. The most prominent differences in cortical activation were observed in the lateralized sensorimotor and posterior parietal areas. Both groups showed activation of right and left sensorimotor and posterior parietal areas during BWS and noBWS walking compared to standing as indicated by significant and sustained mu- and beta-band desynchronization. Interestingly, at the group level, the presence of BWS differentially affected activation of lateralized sensorimotor areas in children with CP and TD. In CP, noBWS walking resulted in greater desynchronization than BWS whereas the opposite was true in TD. However, activation of posterior parietal cortex was not significantly different between groups as BWS resulted in greater desynchronization than the noBWS condition when both were compared to standing.

Implications. We observed significant activation of sensorimotor and posterior parietal areas during treadmill walking with BWS, however, at the group level children with CP had less desynchronization than in typical treadmill walking with noBWS. This result may indicate less cortical activation in the BWS condition which may partially explain the disappointing outcomes of previous randomized controlled trials. Despite finding significant differences between CP and TD at the group level, it is important to note that some individuals within each group showed similar, or even opposite, patterns of activation whereby BWS actually enhanced cortical activity in CP compared to noBWS. These results emphasize the importance of examining individual responses to gait

rehabilitation tasks and the potential for MOBI to play a key role in prescription of personalized gait rehabilitation in children.

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23 Multisensory input improves navigation of patients with hippocampal lesions in a virtual Morris Water Maze

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Spatial navigation is a complex multisensory process that requires the integration of visual, somatosensory and vestibular input and re-afferents from the motor system with mnemonic representations of the environment. Despite this complexity, most human adaptations of the Morris water maze (MWM, Morris et al., 1982) in spatial navigation studies are implemented in stationary desktop-setups that lack the full set of multisensory inputs accompanying real-world navigation. Consequently, these paradigms have limited explanatory power for the processes subserving real-life navigation in humans (Diersch & Wolbers, 2019). Here, we aim to address this issue by exploring the use of a mobile brain-body (MoBI, Makeig et al., 2009; Gramann et al., 2011; 2014) setup in healthy participants and in patients with lesions of the medial temporal lobe including the hippocampus. Hippocampal pathology has frequently been associated with deficits in desktop variants of the MWM (Astur et al., 2002; Feigenbaum & Morris, 2004), indicating the role of the hippocampus as a key structure for navigation across species.

Eleven patients and 22 age- and sex-matched control participants (two per patient) were equipped with a 128-channel high-density EEG system and performed a virtual MWM task in a circular arena surrounded by a wall with clearly visible extra-maze landmarks that allowed for computing an allocentric representation of the goal location. Each experimental block consisted of 7 trials: in the first three trials (learning), participants repeatedly navigated in the arena starting from a fixed location to search for a hidden target, which became visible when approached. In the following four trials, they were asked to navigate back to the remembered location of the target and then press a button (probe). Three out of the four probe trials started from a different location rotated around the center of the arena by 90, 180, or 270 degrees. The target location remained constant within a block but varied between blocks.

For every participant, a set of six blocks was presented in each session. In one session, the six blocks were presented in a stationary (STAT) setup, where the experiment was presented on a flat screen from a first-person view. In another session, the blocks were presented in a mobile (MoBI) setup using HTC-Vive head-mounted virtual reality goggles, allowing participants to move in the physical space. Across the two sessions, the principal spatial layout was maintained, but virtual scenes differed, to avoid memory transfer between the MoBI and STAT conditions. The order of the two sessions was counterbalanced across participants. In all blocks, EEG was recorded continuously. In the MoBI condition, the position and orientation of the feet and torso were tracked.

Overall, significant main effects of setup and group on performance were found, i.e., all participants performed better in the MoBI condition with controls performing better than patients. The interaction between the two factors was statistically nonsignificant. However, the magnitude of improvement in performance in the MoBI condition was larger in patients than in controls. Despite this larger improvement, spatial precision of the performance of patients in the MoBI condition was lower than that of controls in the same condition, implying the role of the hippocampus in encoding spatial information in high precision. A significant interaction between factors setup and participant group was found in mean dynamic time-warped distance between the last learning trial and the four probe trials. The dynamic time-warped distances reflect how closely participants replicated the trajectory from the last learning trial in order to navigate back to the remembered target location in probe trials. The significant interaction indicates that the increase in MTL group's tendency to replicate previously navigated trajectories in MoBI setup was larger than that of control group. On the other hand, the average angular velocity at the beginning of probe trials became selectively larger in control groups in MoBI relative to STAT condition, implying that the ease of rotating the head in MoBI led the controls, but not the MTL group, to look around more at trial onset.

Put together, the results show that both groups' performance improved in MoBI but through distinct navigation strategies. When navigating in MoBI condition, the MTL group showed more trajectory-replicating behavior, and the control group more head-turning behavior. In line with established findings about hippocampal involvement in allocentric coding of spatial information (Feigenbaum & Morris, 2004), it can be speculated that the impairment in allocentric coding caused by the lesion led the patients to use the additional idiothetic/proprioceptive input in MoBI to refine their egocentric representation of space as opposed to allocentric representation.

These findings show that multisensory input and motor re-afferents significantly contributes to successful navigation in real-world environments. In the EEG analysis to follow, we will examine the signal source-localized to the parietal retrosplenial regions, which are known to be involved in multisensory integration and conversion between the view-dependent egocentric representations of space and the map-like allocentric representation.

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24 The effect of genetic Alzheimer's disease risk factors on cerebral blood flow regulation during sit-to-stand transitions in older adults

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Motivation: Neurovascular coupling during mobile behaviors is dependent on tight regulation of cerebral blood flow (CBF) to brain tissue.1 Impaired regulation of CBF through major conduit vessels such as the middle cerebral artery (MCA) is commonly observed with aging and age-related disease1–3 and is associated with impaired electrophysiologic signatures of cortical activity during cognitive tasks.4 The regulation of CBF during mobile activities is poorly understood, particularly with aging. The regulation of CBF during whole-body transitions such as transferring from seated to standing posture,5 a context in which older adults commonly sustain falls, is important for clinical translation in the field of mobile brain/body interactions (MoBI) for rehabilitation. Further, individuals who carry the ε4 allele of Apolipoprotein E (APOE4), the strongest known genetic risk factor for Alzheimer's disease,8 may have greater impairments in CBF regulation6 and demonstrate worse mobility function7 with aging compared to their noncarrier counterparts. The purpose of this study was to 1) characterize CBF regulation during sit-to-stand transitions in older adults, and 2) test the interactive effect of individual APOE4 genotype on CBF regulation.

Methods: Twenty-four cognitively normally older adults, genotyped as APOE4 carriers (n=8) or noncarriers (n=16) completed a single testing session. We quantified CBF by continuously measuring MCA blood flow velocity (MCAv) using transcranial Doppler ultrasound (500Hz) during a sit-to-stand positional transfer. Following 5 minutes of quiet seated posture, the participant was instructed to stand upright quickly and remained standing for 5 minutes. We used a two-way mixed-factor ANOVA to test for change in MCAv over time (baseline: mean MCAv (-15-0s); post-stand: peak absolute value MCAv (0-30s)) between APOE4 carriers and noncarriers. We also compared the onset time of regulatory change (post-stand time delay from initiation of stand to constant increase in MCAv towards baseline levels) between APOE4 carriers and noncarriers.

Results: All older adults showed a decrease in MCAv from baseline (48.07 ± 10.70 cm/s) to post-stand (38.22 ± 10.00 cm/s, Δ = -20.47% ± 11.29%) ($p<.001$). There was a significant group-by-time interaction ($F_{1,22}=5.08$, $p=.035$), in which APOE4 carriers showed a greater magnitude of reduction in MCAv post-stand (Δ = -13.3 ± 6.58 cm/s, -26.00%) compared to noncarriers (Δ = -8.11 ± 4.64 cm/s, -17.71%). There were no significant differences in the time delay to onset of MCAv regulatory change between APOE4 carriers (7.05±3.58s) and noncarriers (5.04±3.89s) ($p=.24$).

Implications: Cerebral blood flow significantly drops in the first 30 seconds during sit-to-stand positional transitions in older adults, which may have implications for neurovascular and cortical activity interactions with body motion. Our results reveal that older adults who carry the APOE4 allele show the greatest reduction in cerebral blood flow during sit-to-stand, implicating the APOE4 carriers may have an attenuated ability to react to the physiologic stress of rapid cerebral hypotension induced by mobile transitions. These findings also highlight the importance of cerebrovascular regulatory responses in the context of behaviorally-relevant mobile brain/body interactions (MoBI) in older adults and support a precision-medicine approach for future mobile neuroimaging studies in aging populations. Future research is needed to test whether attenuated CBF regulation during mobile behaviors is a result of blunted sympathetic nervous system drive, poor neuromuscular contraction and coordination with body motion, and/or impaired feedforward cortical control mechanisms in older adults.

25 Do reaching ability and task-related EEG brain activation measures differ in children with bilateral cerebral palsy compared to those with typical development?

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Introduction: Cerebral palsy (CP) is the most common group of child onset disorders that affect movement, balance, and posture. [1] Bilateral spastic CP is the most common subtype and promoting mobility is a major focus of interventions in this cohort; [2] whereas in unilateral CP, improving manual ability tends to be the major focus. However, children with bilateral CP also may have significant involvement in their upper limbs and in contrast to those with unilateral CP where only one hand is significantly impaired, both hands may have reduced fine motor function. Being able to reach for and grasp objects is a fundamental motor skill throughout life that first emerges around 3-4 months of age. In this study, our goal was to evaluate and compare the temporal-spatial aspects of reaching as well as brain activation parameters from EEG during the task in a group of children with and without CP.

Methods: Participants included 13 children with typical development (TD, mean age: 14.3+/- 2.4 years) and 15 with CP (mean age: 13.4 +/- 2.9 years), all within the ages of 6-18 years. Each child with CP was assigned a Manual Ability Classification Scale (MACS) Level which ranges from I, indicating only minor difficulties with one hand to V, indicating no functional manual ability. Only children from MACS Level I-III who could reach and grasp with both hands were studied here. Children were instructed to reach for, grasp and then transfer three cubes, one at a time, across midline per trial. Each completed 45 trials per hand. Only the reach portions of the task (from start of hand movement to cube contact) were analyzed here. EEG data were sampled at 1000 Hz and processed using EEGLAB functions. [3] These included cleanline, downsampling to 250 Hz, artifact subspace reconstruction (ASR) [4] and independent component analysis (AMICA). ICA weights were applied to the pre-ASR data set to minimize loss of cortical information. Non-brain ICs were removed using the ICLabel plugin [5], and the remaining ICs were used in the calculations for the event-related desynchronization (ERD). The ERD was computed as the ratio of spectral

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power during the task to the rest trial. A general linear mixed model was used to evaluate the effect of group and hand on reach performance and EEG outcomes including the number of independent components, peak event-related desynchronization (ERD), and peak frequency of ERD.

Results and Discussion: Children with CP had a longer, less direct, reach path than those with TD in the non-dominant hand only ($p<0.05$). Reach time was significantly slower in CP in both hands indicating that as a group, those with bilateral CP have impairments in both hands. Reach time and path lengths were greater on the non-dominant hand in both groups. MACS Level was also significantly related to reach times in CP, with slower times in higher levels (rho =0.61; p= 0.02). No significant differences were found between groups or hands (hemispheres) in any EEG metrics, however, several trends in the data are worth considering. Peak mu ERD in non-dominant hemisphere of MACS Level III was less than half of the values in the TD and MACS Level I and II non-dominant hemispheres. The peak frequency of mu ERD was 10.7, 10.2, and 11.3 Hz in TD and CP Levels I and II respectively, and 8.8 in Level III for the non-dominant hemisphere. The mean ages of children in MACS Level II was 14.9 years which was higher, but not significantly from TD or the other MACS Levels, so the lower peak frequency was not due to age differences. We previously reported a similar trend of lower mu peak frequency in CP during walking. [6] Previous literature shows that the frequency of peak ERD is very low in infants and progressively increases with age. [7] It is possible that more severe brain injury leads to slower or abnormal maturation of neural circuits that control movement.

Conclusions. Children with bilateral CP as a group show poorer ability to reach with both hands. While they demonstrate statistically similar ERD changes, the mean trends indicate that those with CP may demonstrate less of a change in power and lower peak frequency with greater levels of involvement. These results emphasize the need for bilateral upper limb assessment and training in bilateral CP, with those in MACS III (or higher) at greatest risk for poor function and EEG differences. EEG may also prove to be a useful outcome measure to complement functional scales when assessing the efficacy of training in CP.

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26 CORTICO-MUSCULAR CONNECTIVITY IS MODULATED BY PASSIVE AND ACTIVE ROBOTIC-ASSISTED GAIT TRAINING

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MOTIVATION. Walking is a complex task that requires the coordinated and flexible activation of several muscles to meet ever-changing environmental challenges. Gait control involves the integration of sensory signals and consequent adjustments in descending supraspinal motor commands and spinal neuronal circuits [1]. Stroke disrupts gait control and affects everyday mobility and quality of life in patients suffering from it. Closed loop rehabilitation that requires patients' active involvement is essential to maximize recovery [2]. Enriched treatments of leg muscles, including the exoskeletons can be used to enhance patients' engagement in the rehabilitation therapy but it is still unclear how best to use them to maximize the outcome [3]. In fact, the brain dynamics underlying sensorimotor control of gait are still poorly documented because of artifacts and technological issues related to neuroimaging during movement, especially in conjunction with robotic gait training (mechanical artifacts). Here we determined the involvement of cortical motor areas in the control of leg muscle activity and how this is modulated by the Hocoma Lokomat exoskeleton for gait training (usually available in rehabilitation clinics) both with and without guidance force and body weight support.

METHODOLOGY. We simultaneously recorded electroencephalographic (EEG), kinematic and electromyographic (EMG) data from 11 able-bodied subjects during gait while wearing the Lokomat, over a treadmill in four 10-minute sessions. During two sessions the Lokomat was set to provide full body weight support and guidance force ("100GF"). During the other two sessions the Lokomat provided only partial body weight support and null guidance force ("0FG"). The order of the sessions was randomized across subjects. Bipolar EMG electrodes were positioned over the Tibialis Anterior (TA), Vastus Medialis (VM) and Biceps Femoris (BF) muscles of both legs. Data were synchronized as described in [1]. EEG data were high-pass (1 Hz) and low-pass (45 Hz) filtered, channels and epochs with prominent non-stereotyped artifacts were manually identified and removed. A subsequent combination of Artifact Subspace Reconstruction (ASR) and Reliable Independent Component Analysis (RELICA) allowed to identify muscle, eye, heart activity and mechanical artifacts (Lokomat). Clean data were then submitted to a source localization procedure [2] and regions of interest (ROI) selected using the AAL atlas. Event-Related Spectral Perturbations (ERSP) of ROIs, time-locked and warped to the gait cycle were compared across conditions. Cortico-cortical connectivity between ROIs and cortico-muscular connectivity between ROIs and muscles (TA, BF, VM) was extracted using the Direct Transfer Function (dDTF). High-level features such as Total Connection strength, Characteristic Path Length, Average Clustering Coefficient, Small Worldness were also extracted and compared between the two conditions (0FG and 100FG).

RESULTS. ERSP data showed a significant activation/deactivation pattern during both active (0FG) and passive gait (100FG). Cortico-muscular connectivity was significantly stronger ($p<0.001$) than muscle-to-cortex connectivity. Also, in both legs, cortico-muscular connectivity was significantly stronger for 0FG than 100FG in distal muscles (TA) with respect to proximal muscles (VM, BF) during the swing phase. On the contrary, for the stance leg, distal muscle cortico-muscle connectivity was lower for 0FG than 100FG. The clustering coefficient, characteristic path length, connection strength and small worldness features were lower during the task with respect to rest, although significance was reached only for the first two.

IMPLICATIONS. Cortico-cortical features show that robotic gait training decreased the tendency for the network to be segregated into sparse clusters, with respect to rest. In fact, the results show that the motor cortex plays a significant role, not only during complex and novel motor planning (e.g., during gait initiation, addressing obstacles, etc.) but also in the control of major leg muscles supporting stereotyped locomotion such as passive walking (100% guidance force) within the Lokomat. The cortex did not merely trigger successive gait phases, but modulated in different and specific ways both distal and proximal muscle activations that effect walking. Cortico-muscle control was modulated by the Lokomat, with a reduction in the control effort of proximal muscles with full guidance force. Given the engagement of the cortex, even when used passively (as in most post-stroke rehabilitation protocols), we conclude that the use of the Lokomat may thus have a significant role in increasing the effectiveness of a post-stroke rehabilitation therapy and worth exploring further.

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27 Electrocortical responses to frequent small treadmill belt perturbations during walking

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Motivation. The anterior cingulate and left sensorimotor cortices are often shown to be involved during a clear loss of balance while walking [1,2]. We recently showed that small and nearly imperceptible perturbations applied on a stride-by-stride basis could disrupt gait stability and that young adults could also adapt to these small perturbations and regain stability [3]. Small perturbations applied on a stride-by-stride basis during recumbent stepping were shown to elicit significant theta band (3-8 Hz) electrocortical spectral power fluctuations in the anterior cingulate [4]. Understanding the underlying cortical processes of balance control during walking includes determining what electrocortical dynamics occur in response to small perturbations, not just large perturbations. The purpose of this study is to determine the adaptation of electrocortical responses to small treadmill belt (acceleration and deceleration) perturbations applied on a stride-by-stride basis. We hypothesized that 1) belt acceleration and deceleration perturbations will elicit distinct electrocortical responses and 2) the anterior cingulate and left sensorimotor cortices theta power spectral fluctuations will decrease with adaptation.

Methodology. Four healthy young adults (2 female) walked at 1.0 m/s on a split-belt treadmill (M-Gait). We briefly (200 ms) accelerated (Slip) or decelerated (Stick) left belt speed by 0.4 m/s at left heel strike or left mid-stance to create four types of perturbations. Each trial included a two-minute unperturbed walking (pre), followed by eight-minute perturbed walking, and concluded with another two-minute unperturbed walking (post). Each trial only had one type of perturbation, and a no-perturbation catch stride occurred randomly one out of every five strides during perturbed walking. We recorded lower body movements using a motion capture system (OptiTrack) and electrocortical responses using a 128-electrode dual-layer EEG system (daisy-chained BioSemi ActiveTwo systems).

We wrote and used custom MATLAB scripts for kinematic data analysis. We first extracted the gait events and calculated the anterior-posterior margin of stability at every right heel strike. To clean the EEG data, we applied, in order, a high-pass filter at 1 Hz, a line-noise filter at 60 Hz (Cleanline), and the template correlation rejection method to reject EEG channels that are highly correlated with gait strides [5]. We then used the step-wise cleaning method to create sets of systematically rejected noisy channels and frames [4]. For each set that the step-wise cleaning method produced, we used adaptive mixture independent component analysis (AMICA) to decompose the data into independent components (ICs) and DIPFIT [6] for source localization. We retained the ICA with the most brain ICs based on ICLabel [7] for the remaining analyses. We used an optimal k-means algorithm with a range of 6 to 10 to identify cortical clusters and then computed event related spectral perturbation (ERSPs) plots time-locked to gait events for each cluster during early (the first third) and late (the last third) perturbed strides to identify any differences in electrocortical spectral power fluctuations as subjects adapted to the small perturbations.

Results. When subjects were initially exposed to the perturbations, the margin of stability in the anterior-posterior direction decreased, demonstrating an initial disruption of gait stability. As subjects gained more experience with the perturbations, they regained their gait stability as stability metrics trended back to pre levels.

Our preliminary results identified four electrocortical clusters (anterior cingulate, left sensorimotor, posterior parietal, and right posterior parietal). Overall, the anterior cingulate and left sensorimotor cortices did not have increased theta band spectral power immediately after perturbation onset for all conditions. Rather, larger spectral fluctuations emerged for the perturbed stride following either a perturbed stride or a catch stride. Overall, our preliminary results did not show distinct electrocortical responses for the belt acceleration and deceleration perturbations. Regarding electrocortical adaptation, the anterior cingulate and left sensorimotor clusters had more

consistent spectral fluctuations coupled with the perturbation events and gait cycle during late perturbed walking compared to early perturbed walking, which had larger spectral fluctuations but were not consistently coupled to perturbation events or the gait cycle.

Implications. These preliminary results did not support our first hypothesis that there would be distinct electrocortical responses to different perturbations but did support our second hypothesis that electrocortical responses would decrease with motor adaptation. The preliminary results suggest that despite the clear adaptation of gait stability to small perturbations during treadmill walking, electrocortical processes are likely coupled with perturbation events and the gait cycle once adaptation has occurred. We will continue to test more subjects to determine if these results hold.

Acknowledgments

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28 Sustained effects of exercise-induced hemodynamic response on executive function during fine motor-cognitive tasks: A functional near-infrared spectroscopy study

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Background: Several studies have shown that acute exercise has a small positive effect on cognitive performance. However, it is still unclear what type of exercise has a sustained impact on cognitive performance during post-exercise recovery. Moreover, although several studies have already examined the sustained effects of acute exercise on cognitive performance on the behavioral level 1–6, only a few have investigated these effects at the neural level during recovery from acute exercise 7–10. Neural mechanisms need to be identified to support the effects of acute exercise on enhanced cognitive performance in post-recovery. Therefore, the purpose of our study was to investigate cognitive performance at the behavioral level, and their neural correlates after a 10-minute post-exercise recovery period with two different types of exercise intervention (High-intensity interval exercise [HIIE] vs. Moderate-intensity continuous exercise [MCE]).

Methods: A total of 29 healthy young adults (7 women) between the ages of 19 and 33 with fair to good cardiovascular fitness were submitted to two different exercise protocols and a recovery session. Cognitive function was assessed using a digital Trail-Making-Test (dTMT). Cortical activity in the left and right prefrontal (frontopolar area: FPA; dorsal lateral prefrontal cortex: DLPFC) and the motor cortex (M1) using functional near-infrared spectroscopy (fNIRS) was measured before, after acute exercise, and during recovery. Each dTMT assessment, a block design, lasts 9 minutes, with a task block alternating 30 seconds of task performance followed by 30 seconds of rest. The whole session of the experiment consisted of five sessions, and the tasks were performed first, second, and fifth while sitting, and the third and fourth performed while walking. The statistical analysis of fNIRS data was performed by comparing the slope and mean of the hemodynamic response.

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Results: During performing the dTMT while walking from pre- to post-exercise, high levels of hemodynamic responses in the prefrontal and motor cortex of the brain were observed compared to the first two sessions and decreased again back to their initial levels in post-recovery, simultaneously accompanied by improvement and maintenance of cognitive performance. Notably, an interaction effect with a medium effect size between session and group (HIIE and MCE) was found only in left M1 post-recovery after exercise, indicating a significant difference between groups ($p = .026$, $d = .873$). This means that HIIE maintained a high hemodynamic response in the left motor area of the brain in post-recovery compared with MCE.

Conclusions: In the present study, a novel comparison was attempted between two types of exercise with different intensities from pre-exercise over post-exercise time to post-recovery time. The results showed increased cortical activation in all measured brain areas from pre- to post-exercise and decreased post-recovery. HIIE, however, showed an increase and maintenance of cortical activation in the left motor area from post-exercise to -recovery, likely due to an additional availability of neural resources for the fine motor and postural control due to the high intensity of exercise. Furthermore, it appears that the available neural resources of the frontal lobe were effectively utilized along with the increase in cognitive performance as a function of the task conditions (sitting and walking) and the two types of exercise (HIIE and MCE). Further studies are needed to complement the limitations mentioned above in future studies. From the perspective of fNIRS statistical analysis, two variables (slope and mean) were considered to interpret the hemodynamic response data. This is a step towards exploring the advantages and limitations of both parameters and a proposal for a new alternative to fNIRS analysis.

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29 Cortical activity during drop-landings with unplanned side- and forward- steps in healthy males: feasibility and relationship between ERPs and task performance

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Motivation: In open-skills sports, movement selection and execution must be continuously adapted with respect to the everchanging environment caused by the actions of other players. Individual's competitive performance is governed by the effectiveness of these complex cognitive-motor interactions, which occur under extreme time pressure and allow for appropriate motor adaptation to the perceived and categorized stimuli. A recent study (Giesche et al., 2021) examined motor-related cortical potentials preceding countermovement jumps with pre-planned (visual cue indicating landing side shown before the jump) and unplanned (visual cue automatically triggered after take-off) single-leg landings. Due to artifacts that resulted from the vertical two-way movement-related acceleration the analysis of visual evoked potentials (VEPs) during the jump was not feasible. The

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motivation for the present study was to modify the experimental setting by using a jump form that requires less body movements and only one-directed movement accelerations (downwards) to potentially reduce the movement-related artifacts and to investigate the cortical processing of visual cues that determine subsequent actions while falling.

Methodology: Ten healthy male participants aged 29.5 ± 8.61 years (BMI = 25.7 kg/m2) performed 64 drop-landings on a force plate (Kistler 4jump, Kistler, Switzerland) from a 60 cm high platform immediately followed by a cut jump to one of 4 predetermined directions. Jumping directions were positioned in a half circular fashion 20° and 60° to both left- and right-hand side from a participant's midline and positioned at 150% of participant's leg length. A blue light sensor positioned in front of the starting platform and 10 cm underneath the participant's non-dominant foot was deactivated by their take-off from the platform, which in turn triggered a yellow light stimulus at one of the 4 jumping directions. Participants received the information about the required jumping directions while falling and upon landing the correct motor command had to be rapidly chosen and executed. The light sensors at the 4 directions were deactivated if the foot landed at least 30 cm in front of them. A successful trial would require a participant to deactivate the sensors in the right and left hemifield with the right and left foot respectively, while maintaining a balanced single-leg stance for at least 2 seconds following the jump. Reaction times (RT; [ms]) for each landing-jump were defined as the time between deactivations of the blue and yellow light sensors. Force plate recorded the contact time [ms] and the peak vertical ground force [N]. Fully mobile electroencephalography (EEG) was recorded from 20 channels (Cognionics, San Diego, USA). VEPs at Oz were extracted in the movement preparation phase while quietly standing on the platform for the blue light stimulation, as well as while falling from the platform for the yellow light stimulation. The amplitude [mV] and latency [ms] of the P1, N1, and P2 components were extracted on the [50, 110], [120, 160], [180, 280] ms time intervals, respectively. The relationship between VEP components and behavioral task performance outcomes was inspected by parametric and non-parametric correlation analyses.

Results: On average, participants performed 73% (± 11.7%) of landing-jump trials successfully. Mean force plate contact time was 502 (± 58) ms while peak ground force was 5657 (± 1327) N. Mean landing-jump RT of the successful trials was 883 (± 91.8) ms while the mean RT variability was 240 (± 201) ms. During the pre-movement (or the motor preparation) phase, clear VEPs were observed in all participants. Mean amplitudes and latencies of the P1 (2.08 mV; 77.7 ms), N1 (-11.7 mV; 140 ms) and P2 (.37 mV; 231 ms) showed no association with any of the behavioral measure previously reported ($p > .05$). VEPs during falling were masked by the superimposed movement-related noise and were proven unfeasible for component extraction following the typical EEG (pre)processing routine.

Implications: This feasibility study aimed to investigate the neurophysiological underpinnings of the cognitive processing that controls complex, unplanned, and ecologically valid alethic movements. The overall goal was to modify the experimental design previously reported (Giesche et al., 2021) to diminish the amount of EEG movement-related artifacts in order to extract VEPs signaling the processing and encoding of to-be-executed jumping directions while falling. Independent component (IC) decomposition was unable to separate the landing-related artifacts from the brain signals, which were consequently both contained within several components. Several approaches to IC rejections will be discussed (Gorjan et al., 2022). Secondly, the non-significant associations between the pre-movement related VEP components and behavioral outcomes might implicate that the cognitive processing occurring at a later time point of such complex movements is a more crucial mechanism that determines the success and speed of these movements.

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30 Prefrontal cortex activation during dual-task tandem walking in young and older adults

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Background. Tandem Walking (TW) is commonly used to assess mobility and stability, which can lead to falls, in various clinical situations1. For the TW test, a participant is asked to walk a specified distance in a straight line in the heel and toe-walk. In general, the TW is more difficult to perform than normal walking because the reduced base of support challenges the postural control system2. Therefore, TW testing may be useful for investigating important aspects of dynamic balance and mobility, especially in relation to pathological aging processes. However, there is little research into how neural resources are used effectively during the TW compared to normal walking. A relatively new approach (Mobile Brain/Body Imaging) from the field of movement science facilitates the integration of imaging methods such as functional near-infrared spectroscopy (fNIRS) or electroencephalography (EEG) and kinematic measurements3,4.The aim of this study was to investigate neural correlates of demanding dual-task situations during TW in young (YA) and older adults (OA). It was expected that this mode of locomotion will have little automation and cause higher dual-task interference.

Methods. We compared cognitive-motor interference on behavioral and neural level between single and dual-tasks in and young (age: 21.4 ± 1.84) and old adults (age: 55.3 ± 3.98). All participants had to perform the tandem walk, cognitive tasks and a dual task (tandem walk and cognitive tasks) in an unspecified order. The cognitive tasks were divided into three sub-tasks: (1) recite the alphabet backwards (mental tracking), (2) recite numbers and letters alternately (task switching, oral TMT-B), (3) count backwards from a given 3-digit number in steps of 3 (mental tracking). All (sub-) tasks were conducted three times. During the task execution, the hemodynamic response (oxy- and deoxy-Hb) of the frontal lobe was recorded using a 8 sources X 8 detectors fNIRS system and gait parameters (i.e. number of steps and error) and cognitive performance (number of correct answers and error) were noted.

Results. Overall, older adults showed a significantly lower number of correct motor, but not cognitive responses than young adults (Wilks Lambda = 0.31, F(10,21)=4.60, p=.002, ⍰2p=.686). In the individual tasks, both younger and older adults performed best in the oTMT-B, followed by the two mental tracking tasks (alphabet, counting backwards in steps of 3). In the DT, there is no difference in YA compared to the ST condition; in OA, performance for the oTMT-B and reciting the alphabet backwards decreases significantly (F(1.36, 40.7)=4.64, p=.027, ⍰2p=.134). OA showed greater motor DT costs than YA for all three cognitive conditions, but only greater cognitive costs for the alphabet backwards task (F(1.57, 47.1)=4.51, p=.023, ⍰2p=.131). The change of prefrontal cortex oxy-Hb in tandem walking for 30 seconds decreased gradually after an initial increase over time, while the gradually increased oxy-Hb in cognitive and dual task over the course of 30 seconds could be observed. In addition, the oxy-Hb during tandem walking was significantly higher in YA than OA at the first 10 seconds. Conversely, during cognitive and dual tasks, oxy-Hb was significantly higher in YA than in OA in the last 10 seconds. In the OA, PFC and DLPFC activation correlated with lower correct motor and cognitive responses, while in YA PFC and DLPFC activation correlated with higher correct motor and cognitive responses.

Discussion. To sum up, we found different patterns of oxy-Hb changes over 30 seconds depending on task and group. Notably, TW showed high oxy-Hb compared to other tasks during the first 10 seconds, which seems to be related to cognitive and executive functions as well as the functions of PFCs involved in gait and dual tasks5. TW, a non-automated gait task, may also induce more neural resources to control posture balance during TW. Conversely, the continuous cognitive load caused by the addition of cognitive tasks during TW led to a gradual increase in oxy-Hb during task performance. This can be interpreted as a different pattern of cortical activation between single- (TW) and dual tasks (cognitive tasks while TW). Compared to YA, the OA showed lower oxy-Hb during dual tasks which seems to be due to the limitation of neural resources in the PFC. This downregulation of neural resources in the PFC may have been redistributed to other brain regions to complement motor control6.

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31 Dual-task performance in hearing-impaired older adults – a MoBI study

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Background: Nearly one of two people beyond the age of 65 years experiences age-related decline in hearing (Goman and Lin, 2016). This negatively impacts psychosocial wellbeing, economic independence, and general quality of life due to cognitive, social and physical aspects (Mick et al, 2014). Hearing-impairments also affect the walking performance of older adults especially when solving more than one task at a time (Wollesen et al., 2018). To develop targeted interventions, e.g., for falls prevention in this target group, it is important to understand the mechanisms of cognitive-motor interference in more detail. As research approach, Mobile Brain/Body Imaging (MoBI, Makeig et al., 2009) was chosen as it allows for the parallel analysis of brain activity and body movements during overground walking. Applying this method to single-task (ST) as well as dual-task (DT) walking conditions in the target group sheds light on the interaction of cognitive and motor processes. It provides the possibility to study cognitive-motor-interference (CMI) reflected in task and walking performance as well as the neuronal correlates. Comparing different dual-task modalities (visual and auditory) reveals how reduced hearing capability impacts dual-task performance in general and modality specific. Furthermore, investigating the group-differences of younger and older healthy adults together with hearing-impaired older adults, enables to specify the contribution of age and hearing impairment.

Methods: We aim at a sample size of 96 (48 healthy and 48 mildly hearing impaired) community-dwelling older adults (50–70 years) and 48 younger adults (20–30 years). A first subset of participants will be recorded and analyzed for this poster presentation. The cross-sectional study has a multifactorial mixed-measure design comparing three groups of participants. The first between-subject factor is age (younger vs. older adults) and hearing impairment (mild versus not hearing impaired) as the second one applies only to the older age groups. Within-subject comparisons will be based on task complexity (ST versus DT) and modality of the cognitive task (visual versus auditory). Visual stimuli will be presented in two mixed colors (cyan and magenta) using an obstacle frame attached to glasses. Auditory tones will be applied in high or low pitch (1000 versus 500 Hz) The discrimination task requires the participant to respond with right or left hand button press according to the presented color or pitch. Stimuli can be further classified dependent on presentation side (left versus right), and presentation-response compatibility (ipsilateral versus contralateral). the OptoGait system provides different gait parameters while Vive trackers (HTC Vive) were used for motion capture of hand wrests, controllers and torso. EEG activity was recorded using 64 active electrodes (LiveAmp, BrainProducts). EEG analysis for the poster will focus on event-related potentials of ST compared to DT for visual and auditory stimuli.

Results: On the poster, the experimental design and setup will be introduced, and the preliminary results of the recorded data will be presented. Cognitive-motor-interference (CMI) will be reported using the dependent variables of task performance (accuracy and response time), gait parameters (Gait speed, step length, double support phase) as well as stimulus evoked brain potentials comparing ST and DT conditions. Derived from these measures the dual task costs will be summarized for the different experimental groups.

Discussion: Based on previous research, we expect that cognitive-motor interference varies between the three groups: young and older adults as well as older adults with hearing impairment. Largest decrements are hypothesized for the hearing-impaired older adults. Behavioral and neurophysiological measures will be used to demonstrate the differences representing the interference of motor and cognitive tasks based on the levels of task complexity. The comparison of auditory versus visual discrimination task reveals the general and modality-specific effects of hearing-impairment during dual-task walking. Performance decrements and the neuronal correlates will

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provide valuable insight into different cognitive-motor processes associated with different aspects of stimulus input, resource allocation, and movement execution . Disentangling the contribution of each of these aspects allows to create more refined interventions that help older adults to cope with the negative consequences of hearing impairment.

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Interpersonal Interaction Posters

32 Contexts of coordination in caregiver-infant interactions and relations to early development

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Human infants depend on their caregivers for survival, and caregiver-infant interactions are critical for early development. Across cultures, mothers interact with their infants through infant-directed (ID) singing and ID speech (Bornstein & Putnick, 2012; de l'Etoile, 2006; Sands & Sekaquaptewa, 1978; Spitz, 1979; Trehub et al., 1993). Although research is beginning to investigate the moment-to-moment dynamics of caregiver-infant interactions (Busuito et al., 2019; Feldman et al., 2011; Field et al., 1989; Moore & Calkins, 2004), few studies have investigated the dynamics of musical interactions. Thus, the current study compares the moment-to-moment interaction dynamics between mothers and their infants during naturalistic ID singing and ID speech. Specifically, we are collecting time series data for movement, gaze, and physiological signals (heart rate [HR]; and skin conductance [SC]) simultaneously from mothers and infants during these interactions.

We are examining interaction dynamics between mothers and infants by comparing the similarity (correlation) of their time series as well as bi-directional information flow between the time series (a measure of how each time series predicts the other). Information is said to flow from one signal to another when the fluctuations in one signal influence upcoming fluctuations in the other signal (Badino et al., 2014; Chang et al., 2017, 2019, 2020). When two adults move synchronously, they also show concurrent physiological synchrony(Gordon et al., 2020; Slovák et al., 2014), and they subsequently cooperate more in games, and report liking and trusting each other more (Gordon et al., 2020; Valdesolo et al., 2010; Wiltermuth & Heath, 2009) compared to when they move asynchronously. Even 14-month-olds are more likely to engage in helpful behaviours with adults who previously bounced to music in-sync compared to out-of-sync with them (Cirelli et al., 2017; Cirelli, Einarson, et al., 2014; Cirelli, Wan, et al., 2014). Information flow has been related to bidirectional social communication (Shockley et al., 2003) and whether two people will "match" in a speed-dating event (Chang et al., 2020). Further, the amount of information flow between the body sways of musicians playing together reflects the rated quality of their music, and assigned leaders influence followers more than vice versa (Chang et al., 2017, 2019). Thus, we hypothesize that mother-infant synchrony may relate to social bonding and social development, while information flow may relate to communication and sensitivity to each other's cues in a bidirectional manner. Further, we expect that ID singing will result in greater synchrony whereas ID speech will result in greater information flow.

Previous studies show that matched gaze and vocalizations between caregivers and infants are associated with increased coordination of their heart rhythms (Feldman et al., 2011), which, when coordinated with behaviours is associated with better infant attachment security (Isabella & Belsky, 1991) and affect (Feldman et al., 2011; Lengua et al., 2007; MacLean et al., 2014); and coordination of SC is correlated with behavioural synchrony between parents and typically developing infants (Ham & Tronick, 2009), and children with autism(Baker et al., 2015). Further, mother-infant SC decreases when mothers sing lullabies, but stabilizes during playsongs, suggesting that mothers use singing to help infants self-regulate (Cirelli et al., 2019). While these studies show a link between early interactions and infant self-regulation, they do not address how mother-infant synchrony and information flow in movement and physiology relate to infant self-regulation.

Mother-infant dyads (N = 4 dyads; 2 to 6 months; data collection is ongoing) were recruited. In the LIVELab at McMaster University, reflective markers were placed on each dyad member's head, wrist and torso, and movements recorded by 12 motion capture cameras (Qualisys). To measure HR and SC, triple point sensors (Thought Technology Ltd.) were worn on the mother's left index finger, and the infant's left foot. To measure gaze, tablets were set up to simultaneously record each dyad member's face. Mothers sat on a piano bench in front of their infant, who was secured in a baby bouncer ~1 m away. To start the interaction, a 2-minute baseline was recorded where the mother silently interacted with her infant without touching them. In subsequent conditions, mothers were instructed to (1) sing songs familiar to their infant, either in a soothing way (lullaby condition) or (2) in a playful way (playsong condition), or (3) to tell the story of the song(s) they sung, in infant-directed speech. Mothers answered questionnaires on personality, mood, language, and music background. Infant self-regulation, social and cognitive developmental outcomes were assessed with the Ages & Stages Questionnaires, the standardized Infant Behavior Checklist and the McArthur Bates, respectively. Mathematical analyses (in progress) will be used to quantify synchrony (Chang et al., 2019; Feldman et al., 2011; Gordon et al., 2020; Moore & Calkins, 2004; Slovák et al., 2014), and information flow (Badino et al., 2014; Chang et al., 2017, 2019, 2020). Specifically, we predict that: (1) ID singing will be more associated with movement synchrony, and ID speech with information flow compared to each other. (2) ID singing will synchronize arousal (HR & SC) between caregivers and infants more than ID speech. (3) Moment-to-moment changes in synchrony and information flow in movement, HR and SC will be related to each other and modulated by gaze. (4) Greater synchrony to ID singing, and greater information flow to ID speech will relate to more advanced infant social and cognitive development. I expect this project will significantly advance the understanding of the moment-to-moment dynamics of naturalistic caregiver-infant interactions during the first year after birth.

33 Decoding attention to self and other during music performance

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In joint action tasks such as group music making, each musician contributes a distinct musical element which collectively form a coherent musical product. As the music unfolds dynamically over time, musicians adjust an array of performance techniques to stay in tune, on time, and balanced with each other in loudness, phrasing, accents, and other expressive features. The temporal alignment (synchronization) in their joint musical output that musicians strive for necessarily relies on precisely predicting how and when the next note will be played; the action-planning involved in playing an instrument makes a reaction-based strategy for playing together inadequate. Achieving this requires a high degree a coordination, and by extension, awareness of each individual's unique sound. Attending intently to sounds produced by fellow musicians, in addition to one's own sound, is crucial for successful performance, but little is known about what musicians focus their attention on or how their target(s) of attention change over time and shift in response to performance constraints.

The remarkable ability of the human auditory system to detect and separate individual sound sources involves the perceptual organization of acoustic features based on their similarity, a process that underlies the Cocktail Party Problem (Alain & Arnott, 2000; Cherry & Bowles, 1960; Griffiths & Warren, 2004). The neural representation of a solitary sound source is hypothesized to emerge in the auditory cortex when responses that encode the source's acoustic features exhibit coherence (similarity over time) (Nelken & Bar-Yosef, 2008; Shamma et al., 2011). In line with such a hypothesis, population neural responses have been shown to encode salient spectrotemporal features of a single speech envelope (Ding & Simon, 2009), and source waveforms from multiple averaged electroencephalography (EEG) recordings correlate with log-envelopes of presented speech (Aiken & Picton, 2008). However, both bottom-up and top-down process likely account for the ability to segregate sound sources (Disbergen et al., 2018), and a growing body of electrophysiological studies have examined the role of attention in auditory stream segregation (Ding & Simon, 2012; O'Sullivan et al., 2015; Shamma et al., 2011; Snyder et al., 2012; Zion Golumbic et al., 2013).

The auditory cortex encodes features of attended sounds to a higher degree than unattended sounds; neural data from cortical surface recordings and EEG are dominated by the spectrotemporal features of attended speech over unattended speech (Mesgarani & Chang, 2012; Vanthornhout et al., 2018). This cortical representation of sound reflects an attention-modulated neural entrainment that enables decoding (classifying) the target of auditory selective attention from single-trial EEG data (Aroudi et al., 2016; Ciccarelli et al., 2019; Mirkovic et al., 2015; O'Sullivan et al., 2015).

A decoding approach called stimulus reconstruction learns a linear mapping from electrode responses to the envelope of an auditory input stimulus, effectively "reconstructing" sound from the brain's response to it. When participants attend to one of multiple competing sound streams, reconstructions of the attended and unattended streams are estimated using the envelopes of the isolated attended and unattended sounds, respectively, as targets in a regression model. Reconstructions can then be correlated with the (isolated) audio streams; greater correlation of the attended reconstruction with the attended stream is considered an accurate classification of the target of attention. This method has demonstrated success in decoding attention to speech using cortical surface recordings (Mesgarani & Chang, 2012), concealed around-ear EEG (Mirkovic et al., 2016), mobile EEG (Straetmans

et al., 2021), and magnetoencephalography (MEG) (Ding & Simon, 2012), but has only once been applied to music stimuli (Cantisani et al., 2019).

We propose a study to investigate musicians' attentional allocation during live music performance using stimulus reconstruction. We will collect EEG data and isolated audio recordings a jazz piano duo while they improvise over the form of a jazz standard piece in a paradigm called trading-in-fours—wherein they 'trade' the leadership role every four bars—and while they perform a pre-composed melody over the form of the same jazz standard. First, we expect that all musicians will attend to the leading instrument to a higher degree than the others during improvisation. Second, we expect musicians to pay closer attention to their own sounds when performing the pre-composed piece than when improvising. Third, we expect that higher subjective reports of self-other merging will accompany performances for which musicians attended to an integration of both instruments.

This approach could provide a real-time physiological measure of attentional allocation during ensemble performance, and evidence for the extent to which self- and other-generated actions are represented in the brains of co-actors in music performance and other joint action tasks.

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Interpersonal Interaction Posters

34 Multimodal Integration for Multiple Subject Musical Hyperscanning

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1 Background

In recent times, behavioral psychologists and neuroscientists have shown an interest towards study- ing the underlying neural effects during social interaction between two or more individuals in a joint activity, such as inter-brain synchronizations amongst participants. Hyperscanning facili- tates this through simultaneous recording of brain activity. It has proven to be a turning point in inter-brain synchronization research [3] through previous studies measuring brain signals during interactive tasks such as decision making, gestural coordination and joint attention [2] [1].

Since the early ages of hyperscanning, musical activities have been one of the most investi- gated forms of social interaction. Playing music demands high levels of cognitive and motor skills. Coordination amongst musicians is an important aspect of an ensemble musical performance and is known to heighten social bonding. Past hyperscanning experiments show significant levels of inter-brain synchronization and coherence in musicians playing together, not only when both mu- sicians play exactly the same music, but also during preparatory metronome tempo setting [4], and during contrapuntal sections [6]. A recent study with nine participants playing drums to- gether presented significant levels of inter-brain synchronization during moments of spontaneous coordinated action. As a control basis, the same group demonstrated significantly lower levels of inter-brain synchronization when asked to follow a metronome [5].

2 Aims

The aim of this project is to investigate inter-brain coherence and synchronization of multiple par- ticipants in a musical context, taking into account not only the musician-musician relationship but also the musician-listener and listener-listener paradigms. To accomplish this investigation, we intend to design a four participant hyperscanning experiment based on low-cost wireless EEG equipment (OpenBCI) with a combination of Lab Streaming Layer (LSL) and MoBI for data syn- chronization. In this setup, two participants shall be musicians and the other two participants shall act as listeners.

3 Main Contribution

Musical interaction has been one of the most investigated paradigms on hyperscanning experi- ments, but no experiment has been conducted based on the musician-listener paradigm so far. By accomplishing this experiment, we intend to provide new information on inter-brain coherence and synchronization in a passive-active scenario that, beyond musical context, can contribute to a better understand of this kind of social interaction.

On the technical side, the cost of hyperscanning equipment is one of the major blocking factors for the dissemination and progress of this research field. By developing a hyperscanning setup based on a low-cost EEG equipment, we intend to facilitate access to hyperscanning research.

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35 Frontal theta power increases during table tennis play – indications for neurophysiological demands during open-skill sports?

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MOTIVATION Exercise taking place in ever-changing environments refers to as open-skill sports and requires dynamic interactions between the individual and its environment (Ingold et al., 2020). The informatory demands in perceiving, processing and integrating visual, auditory and somatosensory cues to adapt behavior suggest an involvement of attentional and sensorimotor brain resources (Gu et al., 2019; Carius et al., 2021). Although mobile electroencephalography (EEG) allows the assessment of cortical dynamics during open-skill sports movement (Hülsdünker et al., 2020), evidence on cortical activation during continuous open-skill sports is still lacking. Therefore, the aim of the present study was to analyze cortical activity during table tennis (TT), a sports categorized as open-skill, and compare it to a motor task (ergometer cycling [EC]) and a cognitive task (n-back [NB]).

METHODOLOGY The experimental design of the present study contained three blocks of each i) TT, ii) EC and iii) NB, performed in a randomized order. During TT, participants played continuous rallies with an experienced person and were instructed to keep the ball in the game for as long as possible. During EC, participants were asked to cycle at a perceived subjective effort of 11 on a visual analogue scale ranging from 6 (easy) and 20 (maximal effort). During NB, participants performed a visuo-spatial three-back task on a 3-by-3 grid. Cortical activity was continuously assessed throughout the protocol and data from 18 healthy students (8 f, 10 m) using a 64-channel EEG system connected to a wireless amplifier (LiveAmp, Brain Products, Germany). Data was preprocessed applying a previously used preprocessing pipeline (Gebel et al., 2019; Lehman et al, 2020; Büchel et al., 2021) including automatic filters and manual artefact cleaning. Applying adaptive mixture independent component analysis (AMICA), the processed EEG data was decomposed into brain and non-brain independent components (ICs) using the ICLabel tool (Pion-Tonachini et al., 2019). Based on all identified functional brain ICs, two frontal clusters were extracted, further referred to as pre-frontal and fronto-central cluster. Power spectral density in the theta frequency (4-7.5 Hz) was computed for all three conditions for all ICs assigned to the pre-frontal and fronto-central cluster. Repeated measures ANOVA was applied to identify within-subject differences ($p<.05$) in frontal brain activation comparing TT, EC and NB.

RESULTS Repeated measures ANOVA revealed main-effects of condition on theta power in frontal ($p<.01$, $\eta_p^2 =0.35$) and fronto-central ($p<.01$, $\eta_p^2 =0.39$) brain areas. Post-hoc Bonferroni tests demonstrated increased theta power in TT compared to EC in frontal brain areas ($p<.05$, $d=1.42$). In fronto-central brain areas, theta power was significant higher during TT compared to EC ($p<.01$, $d=1.03$) and TT compared to the NB ($p<.01$, $d=1.06$).

DISCUSSION The observed increases in cortical activity during TT may serve as an indicator of increased attentional demands during open-skill sports. During TT, individuals are required to integrate visual, somatosensory and auditory information to adapt their behavior and keep the ball in the game. Due to the increased speed, variability and complexity of task-relevant information, it seems that the attentional demands during TT extend those of ergometer cycling, but also complex visuo-spatial cognitive tasks. Based on our findings, TT may serve as a promising neurocognitive intervention in populations requiring activation of frontal brain resources, like children, elderly, or also populations with neurophysiological diseases. From a MoBI perspective, TT may serve as a model to investigate adaptive behavior and its underlying mechanisms in upcoming neuroimaging studies (Carius et al, 2021; Hülsdünker et al., 2020).

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36 Juggling on the moon: Computational neuroscience of skill acquisition

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This project aims to develop a neurobehavioral model of complex skill learning by integrating information from both brain activity and body movement in real time as participants learn real-world activities. Together with an NICT funded team, we will also study the use of novel visuo-haptic VR to provide a slow-tempo method for training tasks that are impossible to slow, such as the juggling of balls, a task requiring precise inter-limb timing and visuospatial processing and motor execution. There has been relatively little study of such a complex motor act, and we have developed methods to jointly analyze movement and brain activity to do so.

We present results from the analysis of a pilot dataset of juggling individuals. We demonstrate that it is possible to reliably extract spatially localized brain activity related to visual processing, spatial attention, multi-sensory integration and motor execution despite movement associated with juggling. Methods used spectro-temporal and connectivity analysis of source-resolved analysis of high-density EEG together with timing events extracted from limb motion capture and videos of ball trajectories.

In parietal cortex, known to be involved in spatial processing, we found robust alpha-band signatures at the moment the thrown ball reached its apex, a time thought to be critical for trajectory estimation required for the planning of the timing and location of the next catch. Motor regions had activity correlated to contralateral hand movements, with broad-band increases around the time of catch. A highly notable finding is narrow-band response between 70-80 Hz that shows sustained activity, but sharp transitions at the time of catching for both hands, signaling a possible role in intra-hand coordination. We are currently analyzing performance and brain activity in terms of three components of juggling skill: throw accuracy, ball trajectory prediction, and timing stability.

37 Neuronal correlates of performance monitoring in a shooting task using VR & mobile EEG

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In almost all everyday actions, people need to consistently monitor and evaluate the status and outcome in real time in order to adjust their behavior if necessary. In the process, the available information is constantly changing, which places very dynamic demands on cognitive processing during performance monitoring.

In order to match this level of dynamics, we implemented a performance monitoring task utilizing 32-channel mobile EEG assessment within a highly immersive virtual reality. Participants shot targets in the VR using either a "laser gun" whose beam immediately hit the targets (i.e., balloons) or using a gun that shot projectiles, whose trajectory could be observed during flight. The latter one allowed for constant monitoring during the projectile's flight phase.

To investigate the temporal dynamics of feedback processing, we computed regression-based ERSPs, considering the outcome, magnitude of error, distance of the target and corresponding interactions to assess these effects on trial level. As expected, errors evoked stronger frontomedial theta (FMT) power than hits. Interestingly, FMT power was independent of the target's distance in the laser gun condition, which would correspond to the difficulty of the trial. However, in the other condition where the flight of the projectile was observable, the target's

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distance affected FMT power. So in these trials FMT indicates the trial specific onset of error processing before the projectile reached the target or eventually missed it.

38 Effects of surface instability on cortical information processing during multi-joint compound movements: an exploratory EEG study

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MOTIVATION: Resistance exercise on unstable surface, known as instability resistance training (IRT), is a key element of musculoskeletal prevention and rehabilitation programs. In general, IRT has been shown to support multi-joint coordination, muscular co-activations and postural stability (Behm et al., 2015). Although unstable surface has already been associated with increased sensorimotor demands (Varghese et al., 2019; Gebel et al., 2020; Büchel et al., 2021), the acute effects of surface instability on cortical processing in full-body multi-joint compound exercises are barely understood. Therefore, the aim of the present study was to explore the effects of surface instability on cortical processing during bodyweight squats.

METHODOLOGY: Force plate (ForceDecks, Vald Performance, Sydney, Australia), electromyography (Ultium, Noraxon USA Inc., Scottsdale, USA) and mobile electroencephalography (LiveAmp-64, Brain Products, Gilching, Germany) data were recorded from 18 healthy young adults (9 female / 9 male, 25.8 ± 4.3 years) during 5 x 20 repetitions of bodyweight squats on both stable and unstable surface (total: 100 reps / condition). To standardize movement execution and muscle contraction times across subjects, the squat cadence was visually guided using a computerized metronome (3s baseline – 1.5s eccentric – 1.5s concentric). Motor behavior was quantified by antero-posterior and medio-lateral displacements of the center of pressure (CoP), as well as the average root mean square (RMS) of the rectus femoris activity. Using source space adaptive mixture independent component analysis (Palmer et al., 2011) in EEGLAB, independent brain components (ICs) were identified and classified based on scalp topography, equivalent dipole location and activity power spectrum (ICLabel, Pion-Tonachini et al., 2019). Subsequently performed k-means clustering revealed 4 clusters (Ø 17 Ss / 30 ICs) based on common dynamic and spatial features of eligible ICs. Cortical activation patterns were computed based on event-related spectral perturbations (ERSP) in theta (4-7 Hz), alpha (8-12 Hz) and beta (13-30 Hz) frequency bands. Moreover, renormalized partial directed coherence (rPDC) was estimated using the GroupSIFT application, which calculates subject-level multivariate effective connectivity for subsequent group-level analysis (Loo et al., 2019).

RESULTS: Bootstrap statistics revealed significantly decreased medio-lateral CoP displacement (39.32 mm vs. 33.24 mm, $p < 0.01$), as well as significantly lower rectus femoris RMS values (72.74 vs. 69.39 mV, $p < 0.01$) in the unstable condition. On the cortical level, temporal activation patterns of the ERSP did not show any significant differences between conditions ($p > 0.05$), whereas rPDC showed significantly increased information flow in theta and beta frequencies from postcentral to frontal superior and cingulum areas ($p < 0.05$) during the concentric phase (1.5s - 3s) of the unstable squat.

IMPLICATIONS: The present experimental framework allowed to investigate mobile brain and body dynamics during multi-joint compound movements on stable and unstable surface. The reduced activation of the rectus femoris and simultaneously decreased medio-lateral body sway may point to changed co-activation patterns of lower limb muscles to stabilize posture during bodyweight squats on unstable surface (Saeterbakken and Fimland, 2013). Furthermore, temporally modulated connectivity in the concentric phase of the squat indicated that surface instability may be associated with a different mode of information processing in sensorimotor areas of the brain (Büchel et al., 2021). However, additional studies are needed to further examine a potential role of these cortical modulations for functional adaptations of IRT programs.

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39 Lower-limb visuomotor reaction speed in healthy young males: Evidence from visual-evoked potentials

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Introduction: Efficient motor responding to a visual stimulus is enabled by fast perception, followed by selection and execution of the appropriate motor response. Behavioural data provide an overall estimation of task performance; however, the underlying neurophysiological mechanisms remain unclear. Recent advancements in wireless technology and the development of algorithms to eliminate movement-related artefacts (Gorjan et al., 2022), made measurements and analyses of human brain dynamics during active movements in natural conditions possible (Jungnickel & Gramann, 2016). The aim of our study was (i) to investigate the feasibility of extracting ERPs that potentially predict lower limb RT (RT) by combining mobile EEG with the sensor-based FitLight trainer system (FITLIGHT Trainer™ Sports Corp, Canada) and (ii) to compare delays in RT between both systems.

Methods: Ten healthy young men (mean age: 30±9 years; BMI: 25.7 Kg/m2) performed a simple (n=100) and a choice reaction time (RT) task (n=100) with their lower extremities. Four FitLight sensors were equidistantly positioned in front of the participants in semicircular order. The left and right outermost sensors were placed at a 60° angle and the inner two sensors at a 20° angle from the point of gravity (distance: one foot length). For the simple RT task, the participants were responding to a single sensor at each position (n=25 for each position). For the choice RT task, 4 blocks of a random sequence (n=25) was used. To measure the accuracy of the Fitlight system the recorded RTs were compared with those calculated from photodiode sensors (gold standard) attached to the Fithlight sensors and connected to a Triggerbox (Cognionics, San Diego, USA). A custom-made pipeline was used for extraction of RTs, and ERP components (P1, N1, and P3 from Oz electrode) evaluation. Paired sample t-test was used for comparison of RTs and multiple stepwise regression analysis with all ERP components entered was performed to predict simple and choice RTs.

Results: Mean lower-limb simple RT (482 ± 51 ms) was significantly shorter ($p < 0.001$) than choice RT (561 ± 53 ms; assessed from Triggerbox data). Although the intraclass correlation coefficients comparing both systems indicated high reliability for both RTs (ICC > 0.992, $p < 0.001$), mean RTs were significantly shorter for FitLight system ($p < 0.001$). Data from multiple stepwise regression showed that simple RT was significantly predicted by the P3 amplitude ($p = 0.001$) and the N1 latency ($p = 0.010$) which combined explained 81% of variance ($R2=0.86$; adjusted $R2=0.81$). Choice RT was significantly predicted by P3 latency ($p = 0.004$) and explained 63% of variance ($R2 = 0.67$; adjusted $R2 = 0.63$).

Implications: Our results show the feasibility of measuring lower-limb RTs in naturalistic environment and that ERP components can be extracted after artifact removal. Such design has potential for future applications in ecologically more valid environments where underlying mechanisms of enhanced behavioural performance can be revealed by studying alterations of ERP components. This has not only potential for enhancing sports performance but also to improve fall prevention in healthy aging populations and patients with neurodegenerative diseases where longer lower-limb RTs were attributed to falls (Lord & Fitzpatrick, 2001; Pelicioni et al., 2020).

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40 Head-mounted display or headphones – Does information processing benefit from cue-modality in a cognitive-motor cued task-switch paradigm?

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Cognitive-motor dual-tasking is ubiquitous. Whilst on the move, we might be processing auditory or visual information from our environment and, with a growing extent, from wearable computing devices like earpods or smartglasses. The latter are increasingly adopted in smart work domains, such as logistics warehouses, to provide ``just-in-time'' information. This constant confrontation with dynamic action-relevant stimuli, across multisensory channels, could place excessive demands on our cognitive resources. According to Multiple Resources Theory, this simultaneous engagement in locomotion and cognitive work could cause interference. This could be detrimental for performance, in particular regarding aspects that require judicious caution, such as where to place our next step on an unstable surface. However, it is unclear whether interference is more likely to occur when processing visual or auditory information while walking.

Using a cued task-switch task, we investigated how participants walking on a dual-belt treadmill coped with variable motor demands (standing, constant walking, laterally perturbed walking). Each trial started with the presentation of a visual or an auditory cue for 400 ms, either using a head-mounted display or in-ear headphones, that indicated the manual response action schema. 600 ms after cue onset, a visual central-flanker stimulus was shown for 1000 ms on a 180° projection screen followed by a fixation cross for 500 ms jittered by +/- 250 ms. We collected subjective workload ratings (NASA-TLX), response measures, as well as electrophysiological data using a 64-electrode mobile EEG set-up from 22 subjects. All EEG measures were calculated relative to the visual flanker stimulus presentation. The main factors: movement demands, cue-modality conditions, and repeat- / switch-blocks were permuted block-wise. Correspondingly, repeated measures ANOVAs (3x2x2) revealed significantly higher subjective workload during: (1) perturbed walking compared to standing and constant walking, and (2) for switch- compared to repeat-blocks. With RT performance, significant interactions were revealed between: (1) modality and task switching, and (2) modality and movement demands. Respectively, larger discrepancies were found between repeat and switch blocks for auditory cues (relative to visual cues) and during walking (relative to standing and perturbed walking.

Stimulus-related EEG measures provided insights into these effects. Using factorial mass-univariate analyses (3x2x2), we found a 2-way interaction regarding N2-amplitudes (150-250 ms) for the factors cue-modality and movement condition. Post-hoc cluster-tests showed decreased N2 amplitudes for auditory trials in all movement conditions, especially while standing. The P3-amplitudes in a centro-parietal cluster (250-380 ms) revealed a 3-way interaction between cognitive task difficulty, cue modality and movement condition. Here, P3 amplitudes were significantly diminished in switch- compared to repeat-blocks, especially during regular or perturbed locomotion compared to standing conditions. This diminution was even more pronounced within visually cued blocks while moving.

These findings demonstrate that highly demanding locomotion conditions and information presentation modality can impact cognitive-motor dual-tasking in terms of performance and neural information processing. While subjective workload was only increased by elevated motor demands and higher cognitive task difficulty (switch blocks), response times were additionally influenced by the presentation modality of cues. EEG correlates allowed the influences of these factors to be better understood. The deployment of higher cognitive functions was diminished in response to auditory cue conditions especially while standing, as parametrized by the N2. The P3 amplitudes as a measure of cognitive resource availability decreased when walking in high cognitive load conditions, which suggests cognitive-motor interference in this paradigm. This effect was even stronger when moving and being presented with visual cues. These findings lead us to argue that the modality of information presentation can have a large impact on resource availability in mobile humans. Especially the presentation of auditory cues was found to be more resource-efficient considering lower response times, lower N2 and higher P3 amplitudes. This benefit was reduced when more difficult cognitive tasks were executed during locomotion, as response times were higher for auditory than visual cues. In conclusion, these results should be considered when designing information presentation for mobile purposes when rapid information and decision processes are involved. Our results highlight that auditory information presentation facilitates information processing of cognitively undemanding tasks while walking. When cognitive task difficulty was increased, this benefit vanished.

41 Underwater balance perturbations modulate human frontoparietal theta band spectral power

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Maintaining standing balance is a whole-body task that requires multisensory integration from spinal and supraspinal neural pathways. Bodyweight support is distributed among lower extremity joints and muscles in opposition to gravitational and inertial loads that create an unstable equilibrium when standing in an upright posture [1, 2]. To overcome gravitational loads, several methods have been used to provide external bodyweight support for simulating low gravity conditions (i.e., deep space) [3-6] or reducing balance demands and lower limb loads during recovery and rehabilitation [3, 7, 8]. Reduced gravity is often simulated in underwater environments by relying on buoyancy of the human body [9]. Postural adjustments and neural control of standing balance underwater have been investigated using lower limb electromyography (EMG) [9], but we understand relatively little about supraspinal neural control processes while maintaining standing balance in water. Prior research using high-density electroencephalography (EEG) to study electrocortical spectral power changes during standing balance on land showed that theta band spectral power from frontal, central, and parietal cortical regions increased during balance instability [10-12].

In this study, we aimed to identify alterations in healthy human electrical brain and muscle dynamics during standing balance, with and without bodyweight support provided by underwater buoyancy, and in response to balance perturbations applied using external underwater fluid forces. Our broader aim is to better understand the neural control of human gait and balance, therefore we also collected data during underwater treadmill locomotion, but we primarily focus on standing balance here. Because standing in water can reduce balance stability [13], we hypothesized that standing underwater would increase balance demands along with theta band spectral power from parietal, frontal, and central regions of the cortex. Greater sensory feedback from the surrounding fluid environment and increased balance demands during balance perturbations caused by external fluid forces could further enhance theta band spectral power increases from parietal, frontal, and central cortical regions.

We measured electrical brain and muscle activities and lower limb motions from five able-bodied participants (age: 22.5 ± 3.5, two male and three female). To do so, we used 64-channel wireless EEG (Brain Products), 14-channel wireless and waterproof lower limb electromyography (7 per limb, Cometa), and two inertial measurement unit sensors placed on the feet during standing and walking. Participants completed five different standing conditions (1) standing on land, (2) standing underwater at pelvis level (~50% bodyweight [14]), (3) standing underwater at chest level (~30% bodyweight [14]), (4) standing underwater at pelvis level with low-level external fluid resistance forces applied in the posterior direction, and (5) standing underwater at pelvis level with external fluid resistance forces in the posterior direction increased by 2.3 times. Underwater treadmill locomotion conditions were also collected for future study. Each condition lasted 3-minutes, and condition order was randomized among participants.

EEG data were analyzed in MATLAB with a customized pipeline based on EEGLAB [15]. After pre-processing the data by filtering and step-wise channel and frame corrections to remove noise, we performed an adaptive mixture independent component analysis (AMICA) [16, 17]. The standing and underwater treadmill walking data were

included in the same analysis. We then separated the standing conditions after rejecting noise components based on ICLabel toolbox [18] and visual inspection from EEGLAB. We used a k-mean clustering approach to group similar brain components among subjects based on brain component location, orientation, power spectra, and scalp maps. Average power spectral density among electrocortical source clusters was then calculated and compared among conditions.

Compared to standing on land, theta band spectral power from prefrontal and parietal cortices increased when participants were submerged in water, while alpha band spectral power decreased from cingulate cortex. By increasing external fluid forces in the posterior direction while standing underwater, theta band spectral power from cingulate and parietal cortices increased, while alpha band spectral power from cingulate cortex decreased.

Our results align with prior studies that showed increased frontoparietal theta band spectral power during balance perturbations [10], and reduced alpha band spectral power from central cortical regions during lower limb sensorimotor processing, including locomotion [19]. Here, we identified electrocortical correlates of increased sensorimotor processing when standing in water compared to standing on land. In combination with increased theta band spectral power and decreased alpha band spectral power during the application of external fluid forces to the lower limbs, these results indicate possible benefits of underwater balance training. By increasing balance demands and sensorimotor feedback at reduced bodyweight levels, it may be possible to stimulate spinal and supraspinal neural pathways under controlled conditions that might not otherwise be possible during recovery and rehabilitation.

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42 Visual demands of walking are reflected in eye-blink evoked EEG-activity

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The cognitive demands of behavior in natural environments are difficult to grasp with neurocognitive methods. While mobile amplifiers may allow EEG to be robustly measured outside controlled laboratory settings, it remains a challenge to extract meaningful event-related EEG activity, which is commonly used to index cognitive demands. This is because the natural world does not, unlike a laboratory experiment, provide discrete and repetitive events to segment continuous EEG activity into interpretable epochs. This study investigates the viability of eye-blink-related activity as a method to circumvent this current limitation. Here, we report on blink-related EEG activity of participants that either stood, walked on a natural grass surface or completed an obstacle course while performing auditory tasks. Blink-related EEG activity discriminated for different levels of mental load during walking. Both, behavioral parameters (e.g. blink duration or head motion) and blink-related EEG activity varied with walking conditions. Early sensory components (N1) indicated attentional allocation while walking but also attentional narrowing at the obstacle course. Later components like the anterior N2 decreased steadily with walking complexity, which highlighted the increased requirement for visual flow integration while moving at the cost of increased cognitive demands. Also ERSPs of Alpha and Theta power indicated specific attentional allocation depending on the demands of the walking task. Thus, eye blink-related EEG activity turned out to be a valuable tool for investigating visual demands during natural behavior.

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43 The influence of idiothetic information on the neural mechanisms of path integration

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Previous research investigating the cognitive processes underlying spatial navigation focussed on the question how an organism orients itself in its environment. The task of spatial navigation requires an intricate interplay of various cognitive processes that are based on and make use of multimodal sensory integration that originates from movement itself, also called idiothetic information (Gramann 2013). The neural mechanisms underlying the processing of such movement-related sensory information is poorly understood. Historically, a major challenge in investigating the neural mechanism of spatial navigation has been the limitations in freedom of movement in most brain-imaging methods (Makeig et al. 2009; Gramann et al. 2011). However, spatial navigation is inherently an embodied process in which various senses such as vision, proprioception, and vestibular information shape the neural dynamics that eventually provide the basis for computing and executing navigation-related behaviors (Etienne and Jeffery 2004). Therefore, studying these neural dynamics while the organism is actually moving is crucial to finding out how the brain supports the complex process of navigation.

Here we investigated the neural dynamics associated with a specific navigational strategy , i.e., path integration. Path integration, or velocity-based navigation (Mittelstaedt 1985), refers to a process in which spatial information on changes in position and orientation is computed based on idiothetic information and thus can rely only on movement-related sensory feedback without prominent visual landmarks or boundary information (Loomis, Blascovich, and Beall 1999). Sensory information thought to be processed by path integration include visual flow, proprioception, and vestibular information. The influence of each of these information sources on the neural dynamics of path integration is unclear however. We used a task called "Triangle Completion Task" in which participants are guided along two legs of a triangle and then have to walk back to the starting point.

To investigate the influence of proprioceptive and vestibular information in path integration, participants performed the same task once in a stationary desktop environment and once in a VR environment that allowed full-body movement. In the stationary condition, participants received only visual flow changes about movement in space using a keyboard as input to control movement. In the mobile VR condition, in contrast, participants actually walked through the environment equipped with an HMD perceiving idiothetic information including vestibular and proprioceptive feedback as well as visual flow.

We collected data from 35 healthy participants with each dataset containing about 1 hour and 15 minutes of simultaneously recorded 128 channel EEG (MOVE, BrainProducts GmbH, Gilching, German) data synchronized to MotionCapture data recorded from the HTC Vive HMD (HTC Vive Pro, HTC Corporation, Taoyuan City, Taiwan) and tracking pucks.

Preliminary results show a pronounced difference in performance between the desktop and the VR condition. Participants not only performed worse on average in the desktop condition but also exhibited much greater variation in their performance. This strongly suggests the importance of proprioceptive and vestibular information in path integration. Even though only sparse visual flow information was available in the desktop condition, performance was not random indicating that some path integration happened even in the absence of other idiothetic information.

We will present EEG data comparing the desktop and full mobile conditions . We will test whether previous results regarding spectral modulations during stationary as compared to mobile navigation tasks (Do, Lin, and Gramann 2021; Gramann et al. 2021). These include strong increases in theta power during active rotations as well as alpha and low beta desynchronization during walking along straight segments. The results will be discussed in light of the neural dynamics subserving natural spatial cognition utilizing idiothetic information.

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44 Human spatial memory and neural directional representations in virtual and real world conditions

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Spatial memory and navigation are a crucial part of our lives. Spatial research and rehabilitation in humans is typically performed either in real environments, which is challenging practically, or in Virtual Reality (VR), which has limited realism. Here we explored the use of Augmented Reality (AR) for studying spatial cognition. AR combines the best features of real and VR paradigms by allowing subjects to learn spatial information in a flexible fashion while walking through a real-world environment. To compare these methods, we had participants perform the same spatial memory task in VR and AR settings. Although participants showed good performance in both, participants reported that the AR task version was significantly easier, more immersive, and more fun than VR. Importantly,

memory performance was significantly better in AR compared to VR. We then ran the AR experiment on healthy participants while they underwent mobile-eeg neuroimaging, and in a patient with a chronic neural implant, focusing on neural representations of task stage, spatial memory and movement. Our findings validate that integrating AR can lead to improved techniques for spatial memory research, such as by showing a clearer movement-related neural signal and novel revealing directional neural representations. Our results also demonstrate the ability to generalize from the wider body of VR based neuroscience research, but also the importance of naturalistic conditions for eliciting proper neural representations.

45 Audiomaze: a novel EEG paradigm toward neuroimaging of real-space navigation

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We investigated the brain dynamics of humans actively navigating in physical space and computing spatial representations of the environment based on discrete sensory information events received through different sensory modalities. Our primary experimental hypothesis concerns the transition of egocentric to allocentric navigational framing; we hypothesized that retrosplenial cortex should be the neural correlate for this process. We recorded whole body motion and high-density EEG signals during subject's freely navigating through invisible maze. Subjects were blindfolded throughout and instructed to use their right hand to detect invisible walls that activates audio feedback. The subject's task was to explore all the branches in each shape of the maze and return to the starting point. There were four different shapes of mazes, and each of them were repeated three times in a row for each. Each subject underwent total of twelve blocks in one session. Motion capture data and EEG data were preprocessed offline using EEGLAB and custom Matlab code. The behavioral results showed that simple mazes can be effectively learned by exploring them in the dark using only proprioception and sparse auditory wall-position feedback, and that this learning is associated with tendencies found in various behavioral measure changes including time to complete, average velocity of motion, and number of performed wall touches. Subject's drawings of maze shapes after finishing each trial indicated that 4/14 subjects could draw the shape of the mazes correctly after three times of repetitions, indicating that the shape of the mental map and behavioral performance may not be strongly associated. EEG data showed that involvement of the retrosplenial cortex was partially

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supported by the EEG power modulation, which demonstrated greater theta-band desynchronization following wall touches after maze learning at right cuneus and lingual gyrus. Finally, information flow analysis revealed tendency of difference between allocentric and egocentric nagivators within centro-central network, and greater information flow decrease in the bate range was found in Trial 3 in allocentric navigators. We conclude that the concept of analyzing brain dynamics during natural behavior was well demonstrated by the current study, and the results indicated that progress of navigational learning is generally associated with decrease of EEG power or effective connectivity in occipital and central regions. This study was reported in: Miyakoshi et al. (2021). Eur. J. Neurosci. 54:8283-8307.

46 Neural Decoding of the Landmark Recognition Process in Urban Settings

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There is a long history of speculation and anecdotal evidence that the design of cities can make wayfinding much easier or more difficult (e.g., Lynch, 1960). However, it is only recently that researchers have begun to pioneer more rigorous methods to study the wayfinding process. Recent behavioral and self-reported data indicates that landmark-use is a crucial aspect of wayfinding in urban settings such as hospitals, airports, train stations, and city exteriors (Joseph, 2006; Epstein & Vass, 2014; Kalantari, 2016; Chang & Zheng, 2016; Sharma et al., 2017). The goal of the current project was to provide additional empirical support for these findings about landmark-use, and to ground our understanding of urban landmarks more firmly in neurological data.

The researchers immersed participants in a high-resolution virtual-reality (VR) urban exterior and asked them to complete various navigational tasks. The participants were outfitted with biometric sensors to collect data through electroencephalography (EEG), electrocardiography (EKG), galvanic skin response (GSR), and head/eye motion-tracking. The use of virtual environments allowed for the collection of robust neurological data while reducing motion- and sweat-related artifacts. In addition, VR allowed the researchers to carefully and precisely adjust the different features of the architectural environment, thus helping to isolate specific design variables in a way that would be impossible in real-world settings.

Our goal was to investigate both behavioral and neurological reactions to different architectural designs during navigation, and to determine if certain aspects of these designs may influence the identification and recall of landmarks. We hypothesized that buildings useful as landmarks would have a high "saliency" factor, which is defined in navigational studies as a striking feature that stands out from the surrounding information terrain (Raubal & Winter, 2002; Sorrows & Hirtle, 1999; Caduff & Timpf, 2008). Beyond this overall hypothesis, we sought to test different types of salient designs to determine what architectural features prompted the strongest behavioral and neurological responses.

The findings confirmed the primary hypothesis that, overall, buildings with striking/unusual features compared to the surrounding terrain were more likely to be used as landmarks. Highly salient buildings were found to attract a greater duration of gazing time on the part of the study participants, and their locations were more accurately recalled on visual memory tests in comparison to non-salient buildings. In addition, the tested neural signatures of spatial awareness, recall, and user interaction were found to be heightened, on average, when participants gazed at the salient buildings as compared to non-salient buildings.

In regard to which design features were most likely to be used in wayfinding, our study produced mixed results. Gaze-tracking data indicated that the participants spent the greatest amount of time looking at idiosyncratic (salient) buildings that had Vertical and Voronoi façade patterns, buildings that incorporated natural elements in an otherwise non-natural context, buildings that had a "twisted" design pattern, and buildings that were unusually tall compared to their surroundings. In regard to the visual memory tests, participants had the greatest accuracy in remembering the location of buildings with Vertical and Voronoi façade patterns, and those with natural elements.

The EEG data showed a variety of interesting and in some cases contradictory results. For example, the neurological responses to buildings that incorporated salient natural elements were the opposite of what we expected, exhibiting a significant decrease in theta activation in the brain's wayfinding centers (based on prior literature, we expected an increase in theta activation for salient buildings). This finding is particularly notable

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since these same building designs scored very highly on the gaze-time data and the visual memory tests. We do not yet have an explanation for this finding, and further research will be needed to see if it will be replicated.

EEG findings for the "twisted" building shapes were also notable, as they showed significant activation in only one of the four wayfinding-associated brain areas that we tested. This building type also scored highly in the gaze-time data, but the location of the twisted buildings was not recalled with greater-than-average accuracy in the visual memory tests. This seems to indicate that some behaviors and neural activations associated with wayfinding may not always necessarily indicate that a wayfinding process is taking place. A salient building may attract attention and incite activation in certain brain areas associated with navigation, but without a landmarking association occurring. The process of landmark-use is complex, and future work in this area will be needed to develop a rigorous body of comparative data.

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47 Brain dynamics of assisted pedestrian navigation in the real-world

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Background. Auditory navigation instructions including landmark information enhance incidental learning of spatial features of the environment compared to standard navigation instructions. This improvement was shown in previous laboratory experiments using driving simulation, video-based as well as real-world pedestrian navigation (Gramann et al. 2017, Wunderlich, Grieger, Gramann, 2022, Wunderlich and Gramann, 2018, 2021a,b). When landmarks in navigation instructions are augmented, navigators correctly recognize these landmarks in subsequent cued-recall tests even after navigating an unknown environment only once and when the test takes place a few weeks after the navigation phase. This kind of incidental spatial knowledge acquisition might be based on changes in visual information processing during assisted navigation. In this case, the use of landmark-based auditory navigation instructions might lead to more attention to environmental features in general.

In order to investigate the impact of landmark-based navigation instructions on incidental spatial learning and the underlying brain activity in an ecologically valid setup, we used mobile electroencephalography (EEG) allowing for free active ambulation in an uncontrolled city environment. Within such a setting, standard events like transient displays of landmarks as known from controlled laboratory experiments are no longer available. To overcome this limitation and to find sufficient numbers of events for event-related analyses of brain activity during navigation, we extracted blinks from the ongoing EEG. Blinks are natural events that represent the onset of visual information intake and thus enable the investigation of the subsequent visual information processing (Wascher et al., 2014).

Method. Twenty-two participants navigated a predefined route through Berlin using either standard or landmark-based auditory navigation instructions. Afterward, in a cued-recall task, participants responded to presented landmark pictures according to the landmark's presence and associated route direction in the previously navigated route.

Brain activity was collected during the entire experiment using 65 electrodes (eego sports, ANT Neuro, Netherlands). The EEG was decomposed using independent component analysis (ICA, Makeig et al., 1996).

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Independent components (ICs) representing vertical eye movement were used to identify blinks and a combination of vertical and horizontal eye movement ICs were jointly used for saccade detection. Gait related ICs were selected to create events for every step. EEG data was further cleaned using IClabel (Pion-Tonachini et al., 2019) and only brain components surpassing 30% braininess were kept for back projecting to the channel level. Using the unfold toolbox (Ehinger & Dimigen, 2019), blink-, saccade-, and gait-related brain activity were deconvolved. The impact of auditory navigation instructions was then investigated in blink-related brain activity of segments where the auditory navigation instruction was provided and of straight segments. Sample-wise comparisons considered the difference to the baseline blink-related activity elicited prior to the first navigation instruction.

Results. The Analyses of cued-recall performance revealed an impact of instruction condition in interaction with the landmark location. For landmarks at intersections, standard navigation instructions were associated with lower recognition rates than landmark-based instruction, replicating previous results.

The EEG analyses revealed characteristic ICs representing horizontal and vertical eye-movement as well as gait features in all participants. The mobile EEG data showed a varying number of ICs classified as brain activity (Mean = 11.9, SD = 4.60, Range = [4 21]). The ICA approach allowed for extracting blink-, saccade-, and gait-related events that could be used to deconvolve the accompanying brain activity patterns. The results demonstrate clear blink-related potentials with clearly identifiable P1 and N1 peaks as well as a prominent late positive complex. A fronto-central and a left-parietal component reflect the differences observed in the performance data.

Discussion. Replicating previous studies, the performance in the cued-recall task indicated that participants using landmark-based instructions incidentally learn more environmental features compared to participants using standard instructions.

Mobile EEG during real-world navigation allows for extracting eye movement as well as gait-related EEG activity. This way, it is possible to dissociate brain activity accompanying cognitive processes from movement-related artifactual activity that would otherwise distort the signal of interest. The use of ICA in combination with Unfold allows for a separation of overlapping activity patterns in mobile EEG. This is potentially providing new insights into cognitive processes like visual information processing in ecologically valid environments reflecting real-world navigation.

The analyses revealed a fronto-central component possibly representing the increased involvement of visual-spatial working memory during assisted navigation. This component was significant especially when the auditory navigation instructions were provided but remained even though less pronounced during straight segments. This adds evidence to the assumption that processing of the environment is induced by landmark-based navigation instruction in a more general way.

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