The Walking Brain: Neural Responses to Dynamic Audiovisual Scenes in Real-World Settings

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Synopsis

Real-world environments are dynamic, complex, and multisensory, requiring the brain to continuously process visual and auditory information during everyday activities. Recent advances in wearable functional near-infrared spectroscopy (fNIRS) now enable the investigation of cortical dynamics during such naturalistic behaviors. In this study, we combine whole-head high-density fNIRS (ninjaNIRS) with mobile eye tracking to examine neural responses to natural auditory and visual input while navigating a complex real-world environment. By modeling time-varying sensory features encountered in these settings, we characterize cortical activity under ecologically valid conditions and contribute to emerging efforts to study brain function in the everyday world.

Background

In recent years, the use of naturalistic paradigms in neuroimaging has gained momentum, enabling a deeper understanding of how the brain processes complex sensory, cognitive, and emotional information. In particular, the use of movies and narratives has substantially improved ecological validity by providing dynamic, continuous, and multimodal stimulation. Previous neuroimaging studies have demonstrated that functional brain networks exhibit time-varying dynamics tracking audiovisual content (Ren et al., 2023). A recent fMRI study showed that BOLD responses in visual and auditory cortex change over time with the movie, with stronger stimulus-driven dynamics associated with higher inter-subject synchrony (Klar et al. 2025). Similarly, diffuse optical tomography during a feature movie has revealed widespread synchronized cortical activation, particularly in hierarchical visual and auditory regions, and feature-based decomposition has enabled mapping of modality-specific cortical responses (Fishell et al., 2019).

Despite these advances, naturalistic neuroimaging research that investigates brain responses to sensory inputs have largely focused on stationary, passive viewing conditions. Here, we aim to bridge the gap between these controlled viewing paradigms and the unconstrained sensory experience of the real world. We extend naturalistic paradigms beyond passive viewing by investigating cortical dynamics during active walking in a real-world environment. We combine whole-head functional near-infrared spectroscopy (fNIRS) with mobile eye tracking, using eye-tracker-based video recordings to capture individualized visual input during navigation. This approach enables feature-based modeling of cortical responses to time-varying sensory information encountered during natural walking, potentially providing insight into brain dynamics under ecologically valid, real-world conditions.

Methods

Simultaneous fNIRS and eye tracking data were collected from six participants during outdoor walking in a complex real-world environment (Fig 1). Subjects walked at their own pace. Whole-head fNIRS data were collected using a high-density system with 56 sources and 144 detectors, yielding 567 channels for each of two wavelengths in total, (O'Brien et al. 2024). The participant's view was captured using the scene camera built into the Pupil Labs Neon eye-tracker. fNIRS signals were analyzed using the Python-based Cedalion toolbox. Preprocessing included SNR-based channel pruning, Motion correction with Temporal Derivative Distribution Repair (TDDR) algorithm, bandpass filtering, and conversion to hemoglobin concentrations changes using the modified Beer–Lambert law.

Time-varying visual and auditory features were extracted from eye-tracker-based video using automated computer vision and audio analysis methods and used for feature-based modeling of cortical responses to dynamic sensory input during naturalistic viewing (Fig 2). Features included sound intensity, luminance, optical flow, and body density. These features were used as regressors in a general linear model (GLM). Short-separation channels were incorporated in the model to regress out superficial physiological signals and minimize contamination from scalp blood flow. Beta coefficients reflecting the relationship between each feature and fNIRS signals were estimated, followed by group-level t-statistics to identify significant cortical responses.

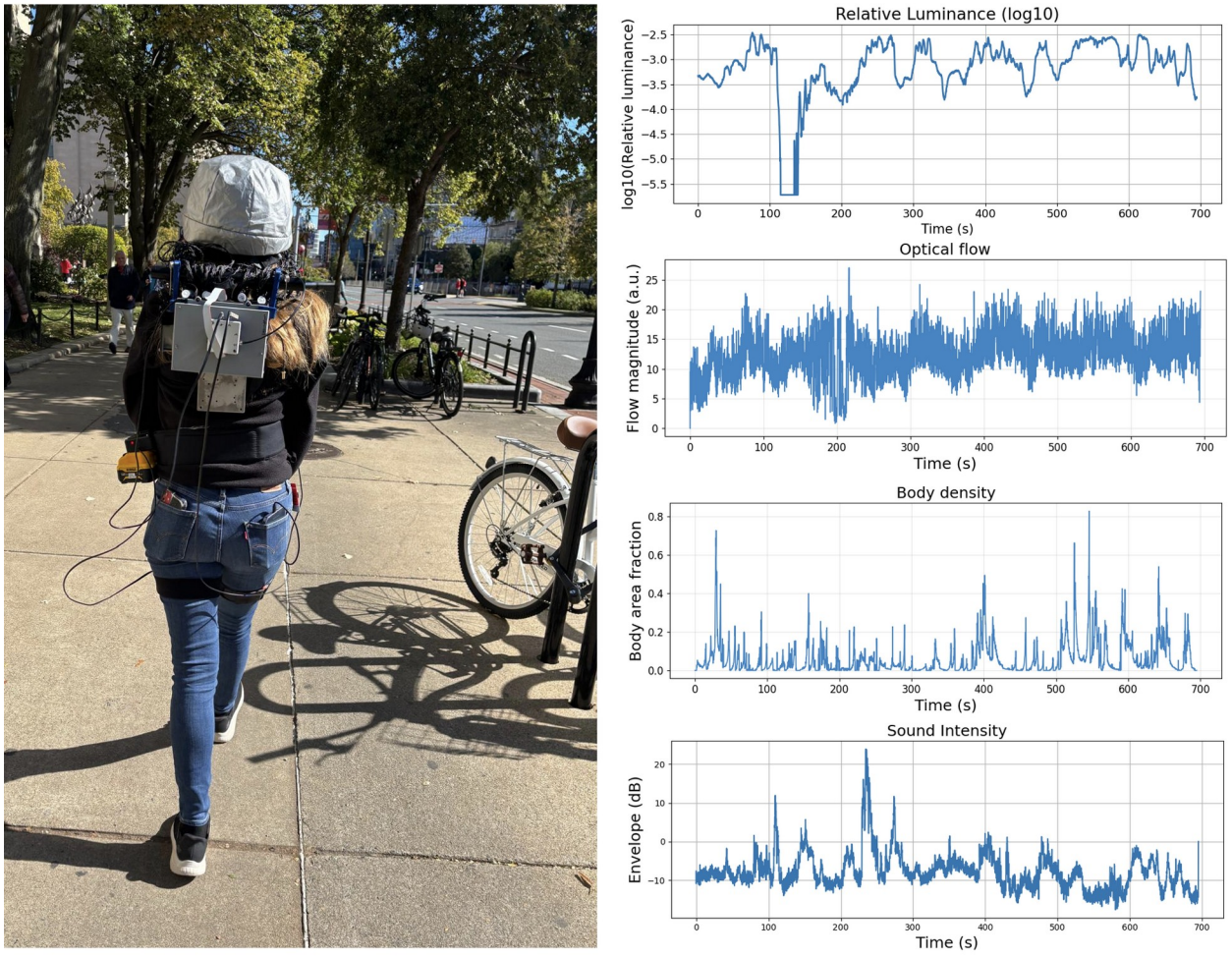

Figure 1. (a) Example of a participant walking down the street while wearing the fNIRS cap and mobile eye tracker (b) Time-varying visual and auditory features extracted from the egocentric scene video during outdoor walking, including luminance, optical flow, body density, and sound intensity, temporally aligned to the fNIRS time axis.

Results

The group-averaged results for each regressor across six participants are shown in Figure 2. As seen from the images, increased cortical activation was observed in regions associated with audiovisual processing. Body intensity, reflecting the dynamic presence of other individuals in the participant's visual field, was associated with cortical response patterns over occipital regions. Similarly, the luminance regressor showed localized cortical response patterns predominantly over occipital regions. Optical flow was associated with response patterns over occipital and superior temporal regions. The sound intensity regressor elicited a diffuse pattern of cortical activation

across the temporal and parietal regions. Together, these initial findings suggest that multiple dynamic sensory features encountered during natural walking may be associated with consistent cortical response patterns, predominantly over posterior and temporal scalp regions across participants.

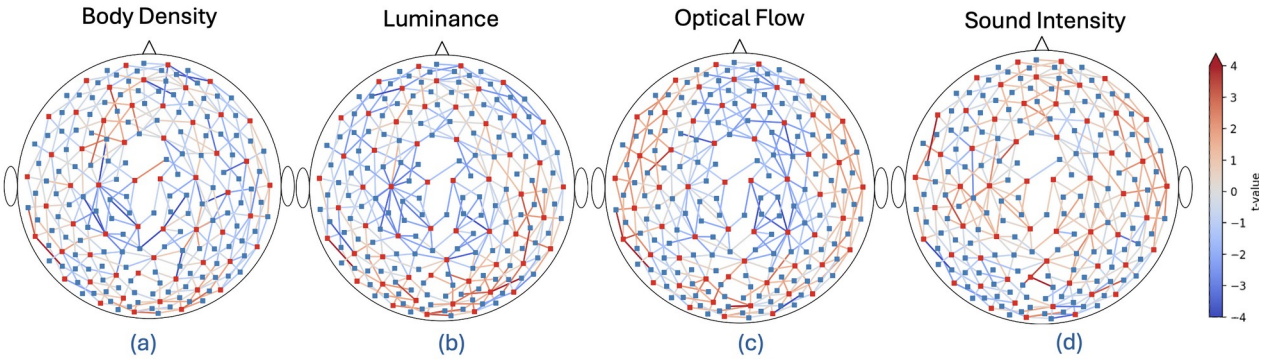

Figure 2. Group-level t-statistic scalp maps for regressors during outdoor walking: (a) body density, (b) luminance, (c) optical flow, and (d) sound intensity. T-values were computed across six participants from subject-level GLM beta estimates of HbO.

Discussion

In this study, we investigated cortical responses to dynamic sensory features during outdoor walking by combining whole-head high-density fNIRS with mobile eye tracking. Our approach extends the well-established "movie watching" paradigm into the everyday world by conceptualizing the participant's egocentric visual experience as a self-generated, naturalistic movie. Our preliminary results show cortical activation in regions associated with audiovisual processing.

Importantly, the present study highlights the value of whole head high-density fNIRS for investigating brain function in complex outdoor environments. Although high-density optical neuroimaging has proven valuable for mapping responses to complex stimuli such as movies in laboratory settings (Fishell et al., 2019), real-world outdoor environments further increase stimulus complexity through continuous multisensory input and active navigation. A whole head high-density fNIRS system (ninjaNIRS) is therefore especially well-suited for studying brain function under these ecologically valid conditions.

Future studies with larger cohorts will increase statistical power and allow examination of individual differences. Expanding the feature space to include eye movements, semantic scene information, and cross-modal interactions will further capture the complexity of real-world sensory processing. In addition, we plan to extend the analysis to image space, leveraging high-density fNIRS to improve spatial specificity and cortical localization.

References

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