

Classification of Infant Sleep/Wake States: Cross-Attention among Large Scale Pretrained Transformer Networks using Audio, ECG, and IMU Data

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Abstract—Infant sleep is critical to brain and behavioral development. Prior studies on infant sleep/wake classification have been largely limited to reliance on expensive and burdensome polysomnography (PSG) tests in the laboratory or wearable devices that collect single-modality data. To facilitate data collection and accuracy of detection, we aimed to advance this field of study by using a multi-modal wearable device, LittleBeats (LB), to collect audio, electrocardiogram (ECG), and inertial measurement unit (IMU) data among a cohort of 28 infants. We employed a 3-branch (audio/ECG/IMU) large scale transformer-based neural network (NN) to demonstrate the potential of such multi-modal data. We pretrained each branch independently with its respective modality, then finetuned the model by fusing the pretrained transformer layers with cross-attention. We show that multi-modal data significantly improves sleep/wake classification (accuracy = 0.889), compared with use of a single modality (accuracy = 0.732). Our approach to multi-modal mid-level fusion may be adaptable to a diverse range of architectures and tasks, expanding future directions of infant behavioral research.

I. INTRODUCTION

Sleep is a physiological and behavioral process central to brain development during infancy [1]–[4]. During the first six months of life, infants spend more time sleeping than awake [5]. Further, indices of infant sleep quality and quantity are associated with subsequent cognitive and language development [6]–[11], attention regulation [12]–[14], social-emotional functioning [10], [12], and physical health [15], [16]. Given the importance of infant sleep to development, automated and unobtrusive monitoring of sleep is critical. Thus, we focus on the task of sleep/wake classification in this study.

Laboratory-based polysomnography (PSG) is the gold-standard sleep assessment for adults and infants alike [18], [19]. However, given the high level of burden and expense of laboratory PSG, researchers have used wearable devices for sleep monitoring [20]. Notably, past studies of sleep/wake classification using wearable devices typically extract sleep features from single-modality data. For example, with actigraphy data, [21] carried out extensive studies on adult sleep/wake

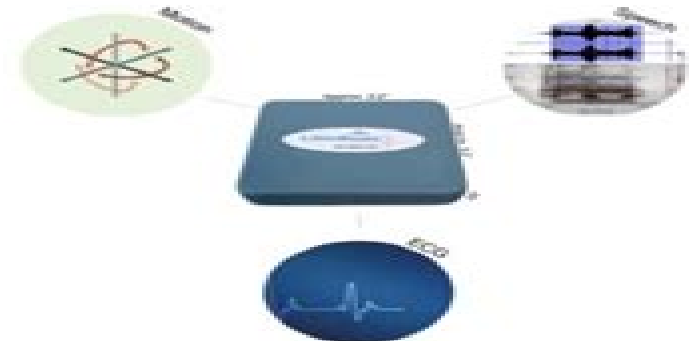


Fig. 1. LittleBeats (center) is capable of collecting audio, ECG, and IMU data. Reproduced with permission from [17].

classification using traditional signal processing methods, classic machine learning methods, and several deep learning methods. Electrocardiogram (ECG) signals are also often used because stable QRS complex and longer R peak period can indicate sleep stages [22]. Studies such as [23] used ECG data to classify adult sleep/wake with a 5-layer convolutional neural network (CNN) concatenated with 2 fully connected (FC) layers. A signal-processing-based approach was suggested by [24], where audio recordings of adults' respiratory sounds were used to estimate sleep/wake likelihood from signal level features such as autocorrelation. All published studies of automatic sleep/wake classification use different datasets, therefore their accuracies are not strictly comparable, but the accuracies reported in all four of these studies are between 81%

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