Design of Wearable EEG Devices Specialized for Passive Brain-Computer Interface Applications

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Introduction

- Recently, the rapid advances in system-on-a-chip (SoC) technology have facilitated the release of wearable EEG devices that can be employed for commercial brain-computer interface (BCI) applications for healthy individuals.
- Generally, these portable EEG devices have been employed for passive BCI (pBCI) applications, such as emotion recognition, mental workload estimation, and attention level evaluation.
- In general, wearable EEG devices employ their own electrode configurations. However, no studies have been performed on the suitability of the electrode configurations for the intended pBCI applications.
- Herein, we present a detailed procedure for designing wearable EEG devices that can maximize the performance for desired BCI applications by utilizing EEG databases associated with these applications.

Methods

Dataset I - Emotion

- ***Data Description***
  - Total 32 healthy subjects with normal or corrected vision (16 females, 19-37 yrs)
  - Signal Acquisition : 32 EEG electrodes with Biosemi ActiveTwo system
  - Watched 40 1-min-long music videos (HAHV, HALV, LAHV, LALV)
- ***Data Analysis***
  - Filtered with 1-55 Hz Butterworth BPF
  - Data segmentation with 1-s moving window having 50% overlap
  - Feature Extraction
    - Power spectral density
    - Differential asymmetry
    - Rational asymmetry
    - Hjorth parameters
    - Shannon entropy
    - Hurst exponent
    - Kolmogorov complexity
    - Higher-order cumulants
    - Common spatial pattern
  - Classified 40 trials into four emotions using SVM with 10×10-fold cross-validation scheme

Dataset II - Attention

- ***Data Description***
  - Total 32 people among the participants from Experiment I (18 females, 20-25 yrs)
  - Signal Acquisition : 32 EEG electrodes with Biosemi ActiveTwo system
  - Human attention test paradigm called "d2-test" was employed
- ***Data Analysis***
  - The procedure from filtration to feature extraction was same as that applied to the emotion dataset
  - A behavioral measure called concentration performance (CONC) which reflects the instantaneous attentional state was calculated
  - Then, the absolute value of the correlation coefficient between the behavioral measure and each of the EEG features was calculated

Determination of Optimal Electrode Configuration

- We designed three types of electrode configurations—emotion-specialized, attention-specialized, and general-purpose configurations—with 2, 4, 6, and 8 electrodes
- The performance of the proposed optimal electrode configurations were compared with the those of the two application-specialized configurations and the electrode configurations of consumer EEG devices

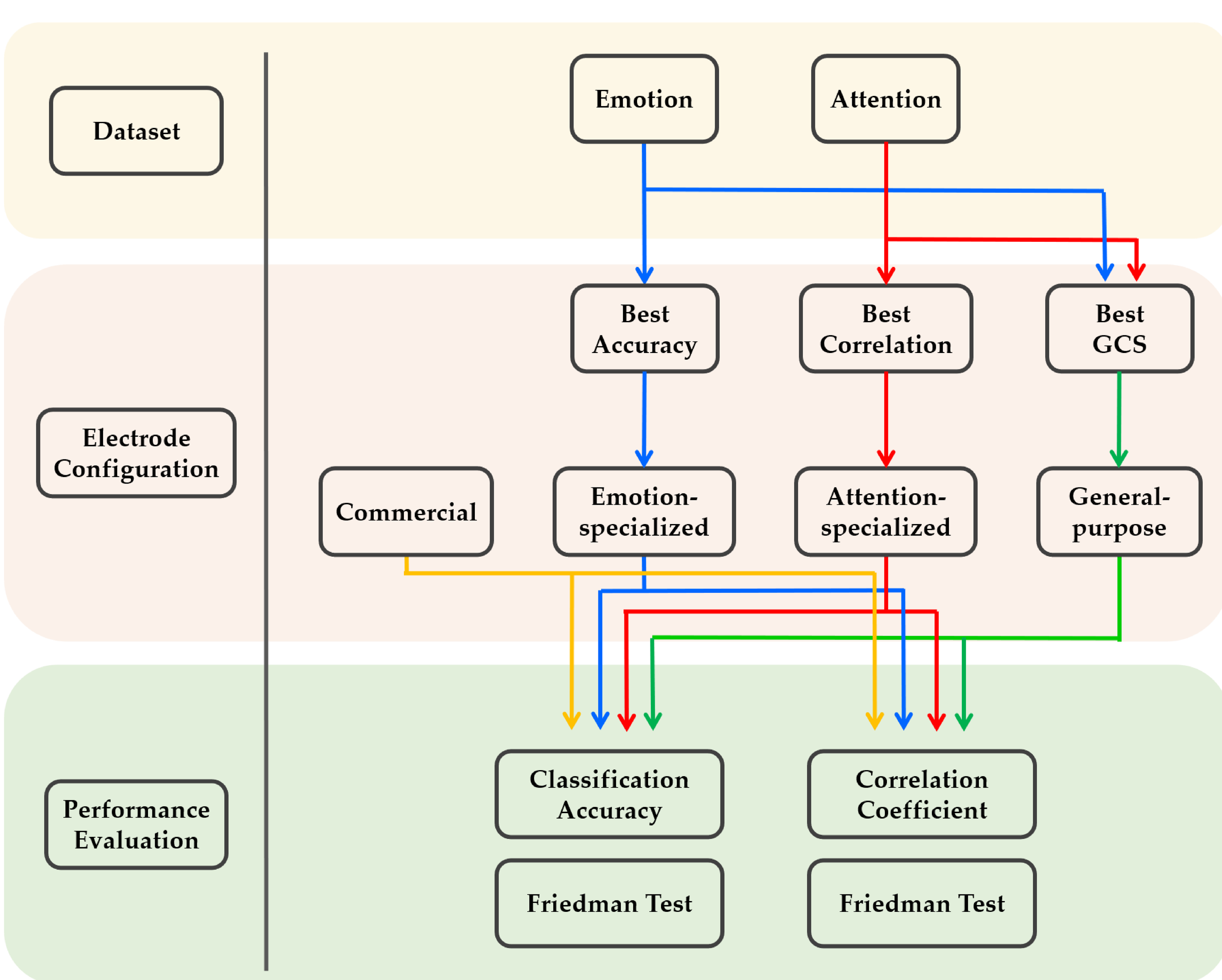

Figure 1. The procedure to determine and evaluate the application-specialized and general-purpose electrode configurations.

Results

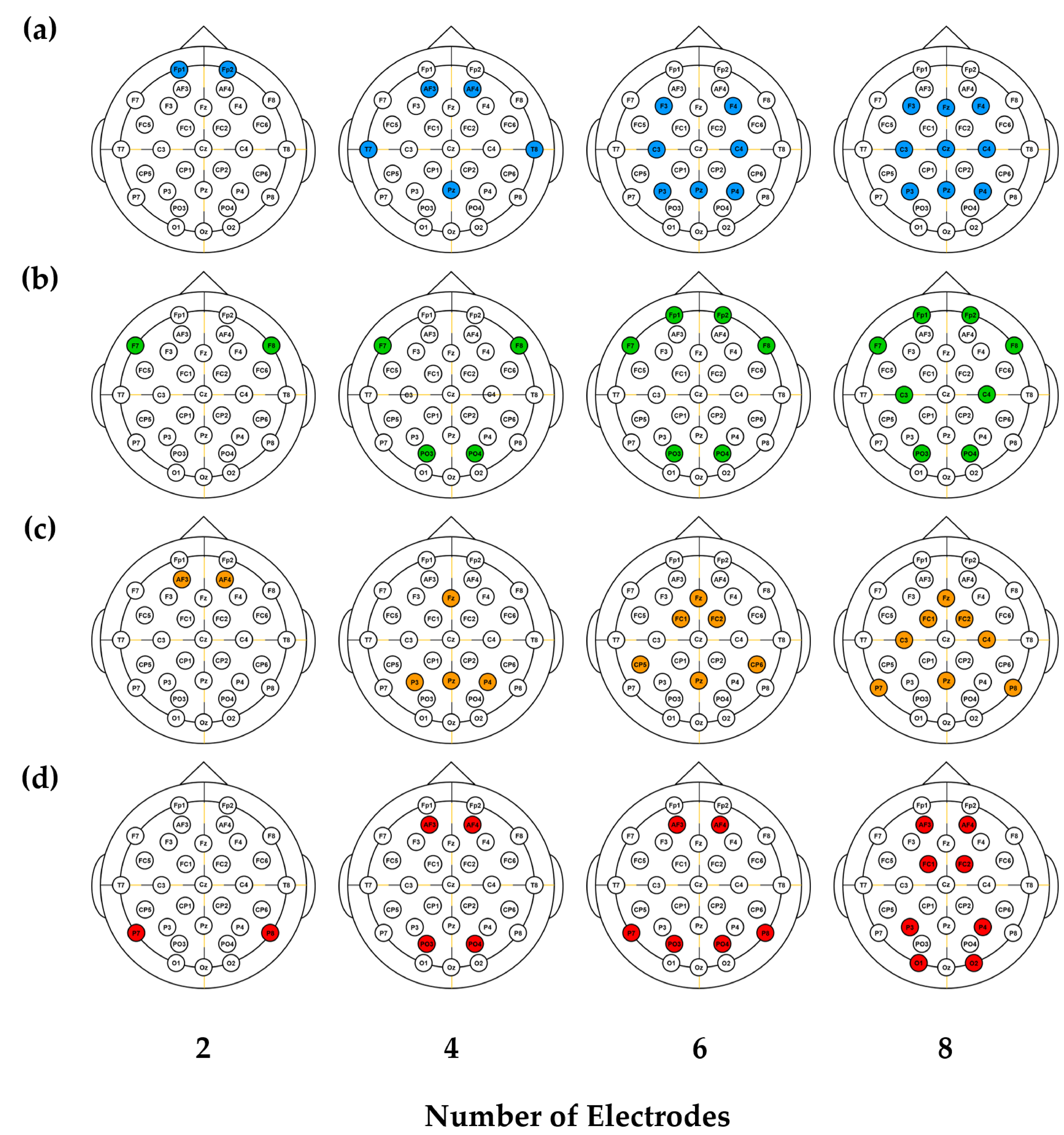

Figure 2. Electrode configurations adopted in this study, with different numbers of electrodes: (a) consumer EEG devices, (b) emotion-specialized design, (c) attention-specialized design, and (d) proposed design for wide pBCI applications. The consumer EEG devices adopted in this study had one more electrode than our designs, except for the device with two electrodes.

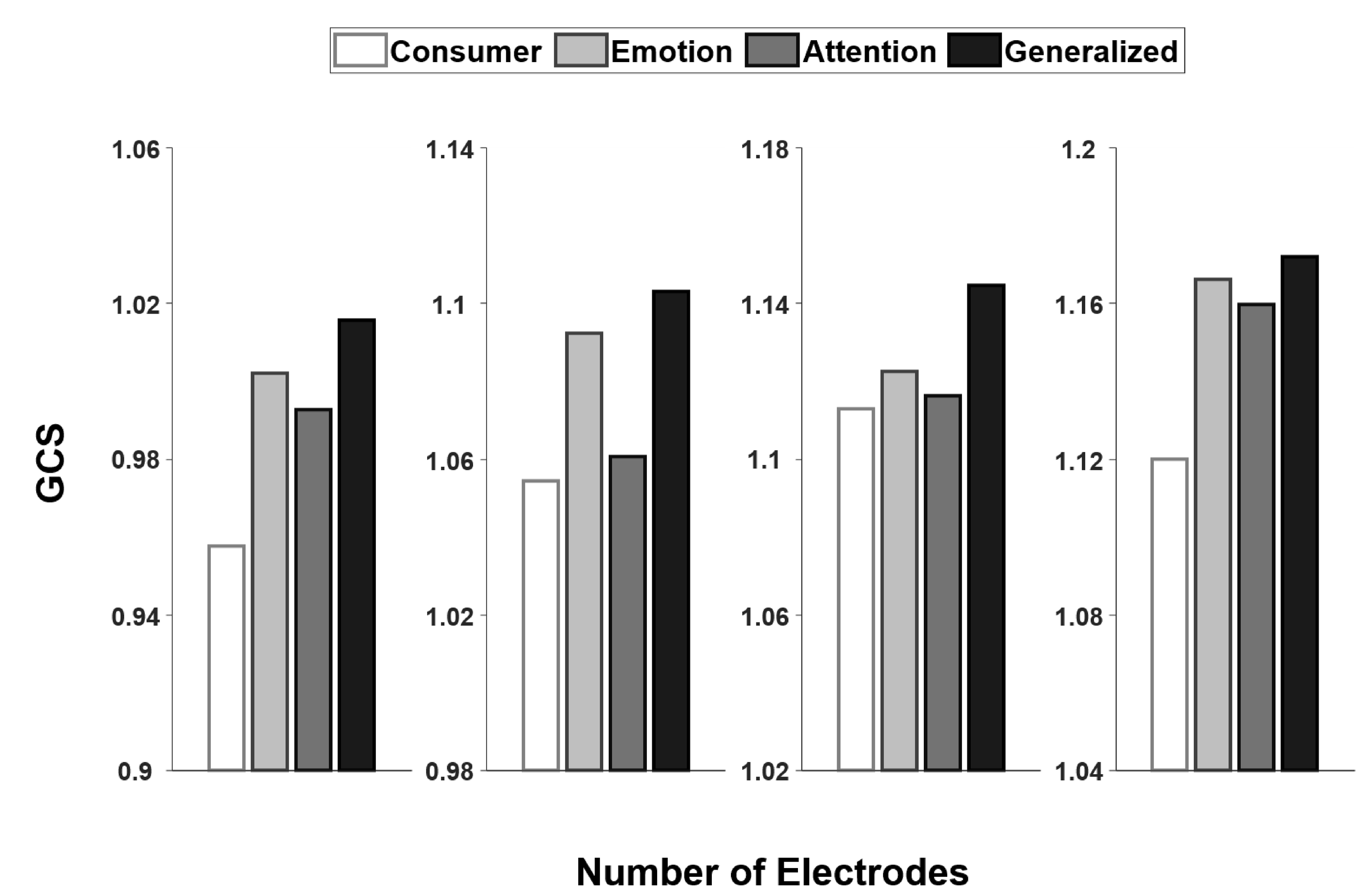

Figure 3. Comparison of GCS values among the consumer EEG device (denoted as "Consumer"), emotion-specialized device (denoted as "Emotion"), attention-specialized device (denoted as "Attention"), and general-purpose device (denoted as "Generalized"), with different numbers of electrodes. There was only a single GCS value for each case.

Discussion & Conclusions

- In the present study, we proposed the general-purpose electrode configurations that can be employed in multi-applications, with slightly lower performances than those of the specific application-specialized configurations but higher performances than those of the commercial EEG devices.
- The general-purpose electrode configurations always exhibited better performance than the consumer EEG devices, regardless of the number of electrodes, even though the number of electrodes in the consumer EEG devices was equal to or greater than that in the newly designed devices.
- Further studies need to be performed to find more generalized electrode configurations that can cover more mental state modulation paradigms and elevate the performance of other pBCI applications based on the estimation of user's mental workload, relaxation, and boredom.
- If the newly released consumer EEG devices are integrated with advanced signal-processing technologies, the use of pBCIs in daily life will be feasible

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