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A systematic review of invasive brain-computer interfaces in humans: current state-of-the-art and features associated with accuracy of an invasive BCI task

Authors: Mervyn Lim Jun Rui[1*], Jack Lo Yu Tung[1], Hong-Yi Lin[2], Wang Yuhang[2], Fong Khi Yung[2], Yeo Tseng Tsai[1]
[1]Division of Neurosurgery, National University Hospital, Singapore; [2]Yong Loo Lin School of Medicine, National University of Singapore
*NUHS Tower Block Level 8, 1E Kent Ridge Road, Singapore 119228. E-mail: mervynlim@u.nus.edu

Introduction: Brain-computer interfaces (BCI) may be broadly divided into invasive and non-invasive types. Invasive BCI is the current gold standard for providing neural signals with the highest temporal and spatial resolution. Advances in the last decade of invasive BCI has resulted in numerous cases being reported on various implanted devices used for decoding and restoring neurological function in humans[1,2]. We conducted a systematic review and individual patient data meta-analysis (IPDMA) summarising the existing international literature on invasive BCI to provide a road-map of the current state-of-the-art in invasive BCI technology as well as to identify features associated with accuracy of completing an invasive BCI task.
Methods and Results: We conducted a systematic review of Medline, EMBASE, and Cochrane databases until March 2022. We included articles reporting primary research on the use of invasive BCI in human patients for decoding or restoring neurological function. We excluded articles that used non-invasive BCI, articles reporting only signal analysis techniques, and articles in foreign languages. The study followed PRISMA guidelines and was registered on PROSPERO (CRD42022324796). 1128 titles and abstracts were reviewed by two independent researchers, and a total of 40 articles were included in the systematic review. Data was extracted using a standardised form, summarised using descriptive statistics, and IPDMA was conducted using multivariate linear regression models.
Invasive BCIs were implanted in patients for control of a digital interface or robot (n=23), identifying the neural correlates of a functional task (n=11), or for neuro-rehabilitation (n=6). Invasive electrodes utilised include implantable electrocorticographic arrays, microelectrode arrays, depth electrodes, and endovascular stentrodes. Data from a total of 94 individual patients across 32 articles performing a BCI task were pooled and the mean accuracy was 81.1 (standard deviation 16.1). The mean age was 33.3 (standard deviation 13.4), 37 (39.4%) patients were females, and 73 (77.7%) patients had epilepsy. Multivariate linear regression showed that female gender (β=7.34; 95% CI 0.05-14.63; p=0.048), as well as sensory and speech tasks (β=19.2; 95% CI 3.52-34.9; p=0.016) compared to motor tasks were associated with increased BCI task accuracy after controlling for confounders.
Discussion and Significance: This systematic review summarizes the progress and state-of-the-art in invasive BCI applications over the last two decades. Advances in invasive BCI technology have resulted in increased accuracy and performance of increasingly complex BCI tasks, including high-performance text and speech communication. Further technological advances in invasive sensors, device stability, and computational algorithms will continue to improve BCI performance in the future.

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