

Volitional BCI: Designing for agency in invasive brain computer interface

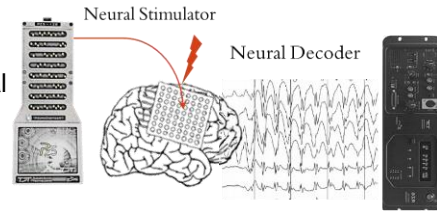


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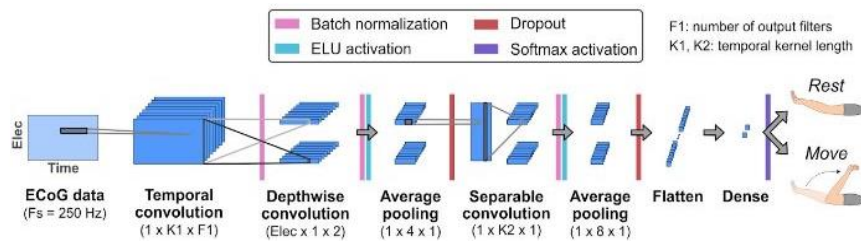
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Brain-computer Interface (BCI) Architecture

Brain-computer interface (BCI) systems use electrode arrays implanted at multiple locations in the brain. This enables the device to direct input to the brain via electrical stimulation of neural tissue and allows for simultaneous recording of the brain's electrical activity (i.e., decoding) into outputs such as movement (e.g., for Parkinson's Disease).



Algorithms for BCI Stimulation/Decoding



Advanced deep learning (DL), and artificial intelligence (AI) enable this input/output communication pathway with the brain. However, these complex models are often not interpretable, which may limit the ability of BCI users to understand and make deliberate choices about the function of their BCI. We argue that BCI designers are obligated to optimize for user agency. Furthermore, we advocate for a participatory co-design approach, where BCI users are equal partners in the research process of designing their BCIs.

Agency & Volition

Agency: The capacity to act and influence one's surroundings (closely related to autonomy). In the context of BCI, agency represents the end-user's ability to dictate the action of the implanted technology.

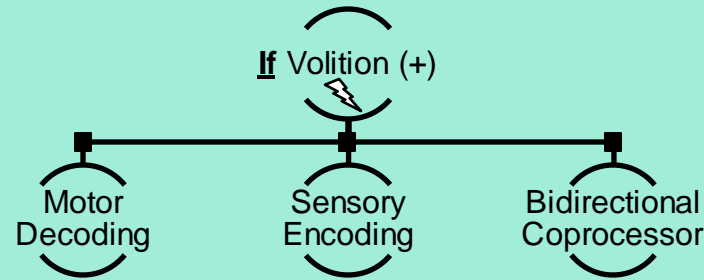
Volition: The ability to intentionally operate a BCI at-will and in the manner of one's choosing.

At-will: The operation is consciously and intentionally chosen.

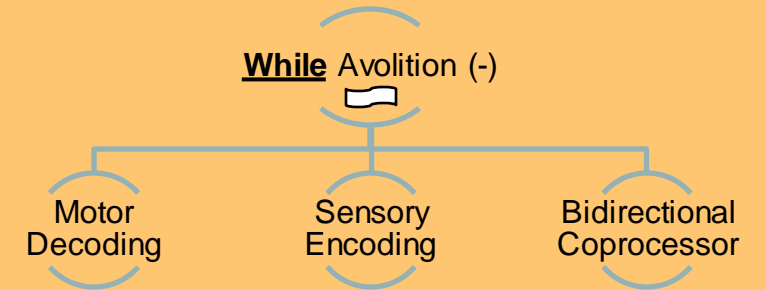
In the manner chosen: The operation occurs in accordance with the user's intentions.

Volitional BCI Architectural Features	Example Framework Considerations
Gating Positive or negative: whether a user consents to operate (positive) or declines to stop operating (negative) the BCI	dynamism, autonomy, modularity
Permission Triggered or continuous: whether the user must constantly consent or decline operation, or whether the permission is true for some period of time	dynamism, transparency
Querying Active or Passive: whether the user provides volitional control through a passively decoded state variable or response to an active query	autonomy, transparency

Example Volitional BCI Architecture Proposals & Features



- +** **Gating: Positive**
user consents to operate the BCI
- ↕** **Permission: Iterative ('If')**
user repeatedly consents or declines
- ⚡** **Querying: Active**
user responds to an active query



- **Gating: Negative**
user declines to stop BCI operation
- ∞** **Permission: Continuous ('While')**
user's decision persists over time
- 🏳️** **Querying: Passive**
volition is obtained by passively decoding a state variable

Questionnaire for Volitional BCI

Framework Considerations	
<u>Locus</u>	Who determines whether the BCI is operational?
<u>Dynamism</u>	Is the operability of the BCI static (e.g. external switch) or is it responsive to a state variable (which may be updated)?
<u>Autonomy</u>	Is the operability of the BCI dependent on a state variable decoded by the BCI?
<u>Modularity</u>	What are the core functions of the BCI (e.g. decode motor output, decode cognitive state, encode touch input, encode visual input)?
<u>Transparency</u>	Does the user know when the BCI system or individual functions are operational?

Conclusions & Applications

BCIs are not currently optimized toward agency.

Agency is a key neuroethical consideration and principle of good BCI design

BCI engineers must optimize volitional control to users' needs.

Particularly considering increasingly 'black-box' decoding & encoding methods

Including users as partners in the design process will yield insights regarding what the user actually wants from their BCI.

That is, allowing for participatory co-design of the BCI.

We propose Volitional BCI architectures & considerations.

We believe future BCIs should consider implementations that account for volitional control and user co-design.