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# Multimodal Data Fusion for Brain-Computer Interfaces

## A literature review

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### Context

Several factors have made medical progress in neurosciences possible, including optimization of the patient care:

- New **data acquisition technologies** combined with the multiplication of health data;
- A lot of different data to describe a patient's **physiological and physical state**;
- New algorithmic methods able to integrate these different **modalities**.

**Brain-Computer Interfaces** (BCI) usually take electroencephalograms (EEG) signals as single inputs. However, studies show that **hybrid systems** such as **Body-Computer Interfaces**, combining the advantages of different types of input signals, offer competitive results compared to conventional interfaces [3,5].

### Problematic and objectives

The purpose of this work is to **complement** current research on hybrid BCI [4].

**How to integrate different modalities at the scale of the algorithms in BCIs?**

The objectives are the followings:

1. Conduct a **literature review** focusing on multimodal data fusion methods that could be integrated in hybrid systems.
2. Identify relevant **combinations** of physiological signals for improving traditional BCI systems.
3. Compare above-mentioned methods.

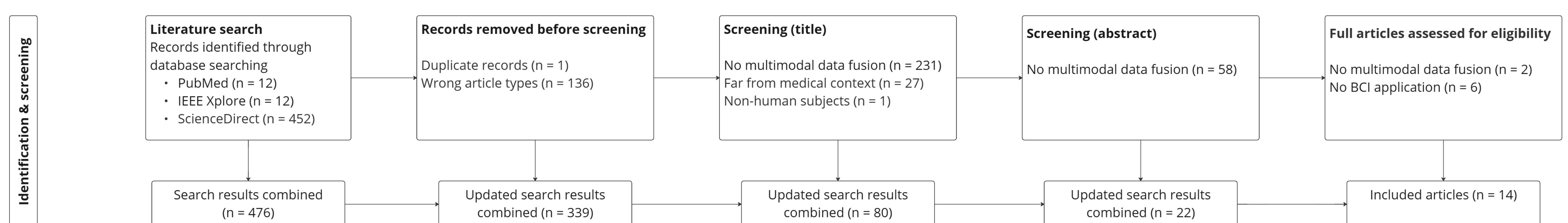
### Methods

This study is part of a comprehensive literature review, conducted according to PRISMA recommendations, on deep learning data fusion mechanisms. The review is currently being written.

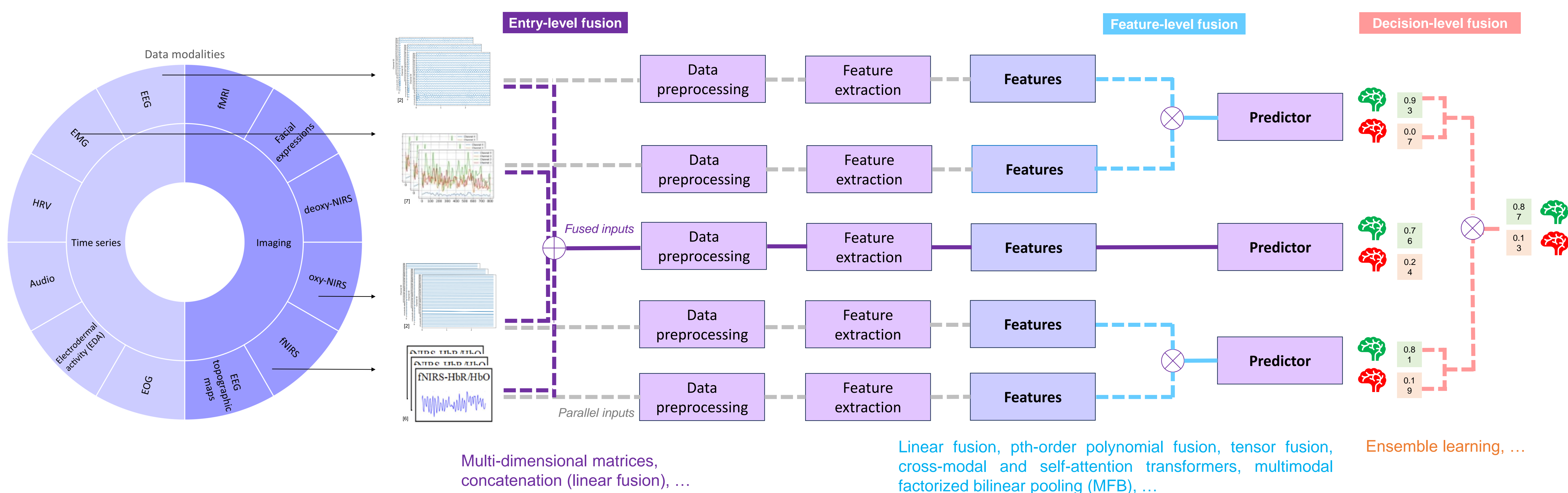
The comprehensive search depicted here was based on several databases. A total of 339 articles were screened.

The diagram below represents the contributions of this research, applied for BCI, adding 14 more articles.

### PRISMA diagram



### Different levels of fusion mechanisms



### Methods and limitations

- **Entry-level fusion**: a shared representation is learnt from a **multimodal single input** formed by the fusion of all data at the entry level of the network. **Non-linearity of correlations between data limits learning** [8].
- **Feature-level fusion**: multimodal features are **learnt independently then concatenated** at a deeper level to better learn correlations later. **Difficulties lie in the weight given to each feature, regardless of its dimension, as well as the size of the feature vector** [1].
- **Decision-level fusion**: **same independent decision-making** process for all data whose results are combined at the end-level. **However, final result is based on independent input processing without learning modalities correlations** [8].

### Conclusion

Different modalities can be interesting but complicated to integrate without complicating nor degrading the algorithms. Rationale behind fusion strategy highly depends on **relationship between data**. Relationship is given by the consistency of specific **patterns concomitant** with the occurrence of the target event of the BCI: thus, multimodal inputs must represent the same recording time at the same scale. Ideally, models should combine **independent and correlated analysis** of each normalized modality to accurately learn multi-modal patterns. Thus, **adapted feature-level fusion** seems the most appropriate. Such method showed promising results in motor imagery classification with a reported accuracy of 82.11% [6].

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