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Building a taxonomy of variability factors in active BCI

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Introduction: BCI performances are significantly affected by variabilities, both **inter- and intra-user** [1]. While there are advances in Machine Learning (ML) to deal with them, the understanding of the specific variability factors affecting BCI performance and EEG features remains limited. Thus, we are conducting a literature review to identify known variability factors and propose a taxonomy of them.

Methods: We conducted a literature review using the PubMed database, focusing on studies involving EEG-based active BCIs. The search query used was: ("Brain-Computer Interface" OR "BCI" OR "Brain Computer Interface") AND ("non-stationarit*" OR "non stationarit*" OR "nonstationarit*" OR "variabilit*") AND ("active" OR "mental tasks" OR "motor imagery" OR "spontaneous"). This search initially yielded 177 articles. We then excluded studies focusing on passive or reactive BCIs, those using a main neuroimaging method other than EEG, or those unrelated to the BCI domain, leaving 155 articles. Next, we classified the articles into four main categories: articles focusing on **"inter"** or **"intra"** user variability factors, those addressing **"both"**, and **"method"**—articles addressing ML methods to manage general inter- and/or intra-user variability without investigating its causes.

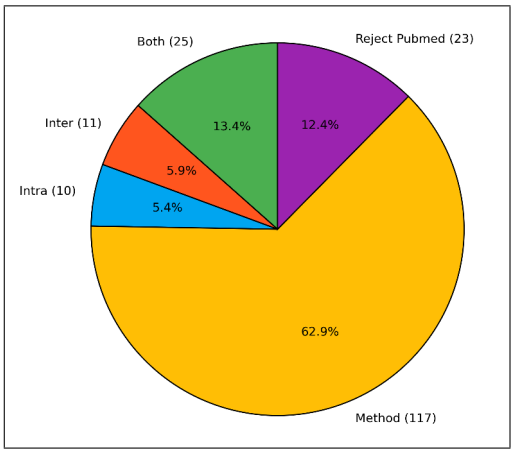

Figure 1: *Categorization of the 155 queried articles. 117 were classified under "Method" (yellow), 25 under "Both" (green), 11 under "Inter" (orange), 9 under "Intra" (blue), and 23 were rejected (purple). 8 papers were counted twice as they fall into two categories.*

Results: The majority of studies focuses on methods (62.9%) to manage variability, with limited attention to the factors causing it. Studies addressing inter-user variability constitute 5.9%, intra-user variability 5.4%, and both 13.4%, (see Fig. 1).

Discussion: This distribution stresses the need for more studies on the factors causing variability on BCI performance and EEG features, and on their effect. Inter- and intra-user variability factors can be broadly categorized as: **Experimental settings**: Experiment design or environment (e.g., electrodes position, task type, instructions, feedback, time of day, lab vs. home setting) [2]; **Individual traits**: User-specific demographic or cognitive characteristics (e.g., age, lifestyle habits, personality, attention span or visuo-motor coordination) [3]; **Structural Anatomy:** Anatomical attributes, such as gray matter density or cortical thickness [4]; **Physiological activity:** Non-neural signal (e.g., heart rate variability, muscular or ocular activity) [5]; **Psychological states:** Temporary mental or emotional states (e.g., mood, motivation, mental fatigue or frustration) [1]; **Neurophysiological activity:** Changes in brain activity (e.g., ERD/ERSs amplitude, Sensorimotor Rhythms at rest; band-power/spectrum fluctuations) [3]. Future work will include a more comprehensive review and a dedicated experimental campaign to systematically assess several variability factors, aiming to develop more robust BCIs.

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