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Neuroanalytic and Summative Evaluation of Undergraduate Candidates: Criteria Based on Transversal Competencies

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Abstract
This study explores critical thinking as a key transversal competency, focusing on its neurocognitive processes through Electroencephalography (EEG) analysis during a critical thinking test. Conducted with 18 undergraduate students at Tecnologico de Monterrey, the research employed the Watson-Glaser Critical Thinking Appraisal II, a standardized test. EEG data were recorded using a 16-channel system, with signals pre-processed to extract Event-Related Potentials (ERPs). Results identified two main ERP components: N200 and P275, associated with Error-Related Negativity and Positivity, respectively. However, no statistically significant differences were found between correct and incorrect responses. The findings, while inconclusive regarding neural differences in response accuracy, highlight different ERP components when students response correctly or incorrectly. This research advances in neuroeducation, offering insights into the neurophysiological foundations of critical thinking and providing a basis for improving evaluation and development of transversal competencies in educational contexts.

Keywords: *Transversal competencies; Critical thinking; Electroencephalogram (EEG); Event-Related Potentials (ERPs); Neuroeducation; innovative education, higher education.*

1. Introduction

The continuous evolution of knowledge has reshaped education, emphasizing skills that enable individuals to adapt to complex environments. Transversal competencies, such as critical thinking, communication, and ethical awareness, transcend disciplines and are essential for modern education (Alsina et al., 2011; Salcines et al., 2018; Yániz & Villardón, 2006; Vincent-Lancrin et al., 2019; Pellegrino & Hilton, 2012).

Critical thinking, defined by Glaser (1941) and expanded by Watson and Glaser (1994, 2010), involves evaluating evidence to form logical conclusions and solve open-ended problems (Thagard, 2011; Dwyer et al., 2014; Halpern, 2014). While its role in education is well established, its cognitive neuroscience aspects remain underexplored (Butler et al., 2017).

This study addresses this gap by combining the Watson-Glaser II Critical Thinking Appraisal with EEG technology to investigate the neural basis of critical thinking. Previous attempts, such as Shaddock (1981), relied on outdated EEG systems and did not assess real-time task performance, such as the precise tracking of neural activity during complex reasoning tasks proposed by Kappenman & Luck (2016). This research advances the field by directly capturing EEG data during critical thinking, providing novel insights into its neurophysiological mechanisms.

2. Materials and Methods

2.1. Participants

The study involved 18 final-semester Biomedical Engineering students aged between 20–23, 10 males and 8 females with an A-B socio-economic from Tecnologico de Monterrey. Inclusion criteria included written informed consent, while exclusion criteria involved withdrawal or incomplete procedures. Ethical compliance followed the Declaration of Helsinki.

2.2. Materials and Equipment

The critical thinking test, developed by Assessment Day Ltd., featured five sections: 1) Arguments, 2) Assumptions, 3) Deductions, 4) Interpreting Information, and 5) Inferences. Instructions and example questions preceded each section, with responses recorded via keyboard. Breaks between sections minimizing fatigue, ensuring reliability.

EEG signals were recorded using the g.USBamp system (g.tec Medical Engineering), a 16-channel FDA-certified amplifier with Type II security and biocompatible conductivity gel. Impedance was kept below 5 kΩ, and signals were digitized at 256 Hz for analysis.

2.3. Experimental Procedure

The experiment consisted of a 73-minute session organized in six stages. First, participants were informed for 10 minutes about the research aims and the consent form. Second, electrodes were collocated in accordance with the International 10/20 System and the EEG system was calibrated (10min). Third, participants at rest were registered for 3min. Finally, the critical thinking test was applied for 50 minutes.

2.4. EEG Paradigm

Participants completed five subtests, each containing 3–7 questions per problem. Problems were displayed at the top of the screen, followed by questions and multiple-choice answers. Participants responded via keyboard, with a 1-second interstimulus interval (ISI) and a 5-minute break after each subtest. The design of the critical thinking task is shown in Figure 1.

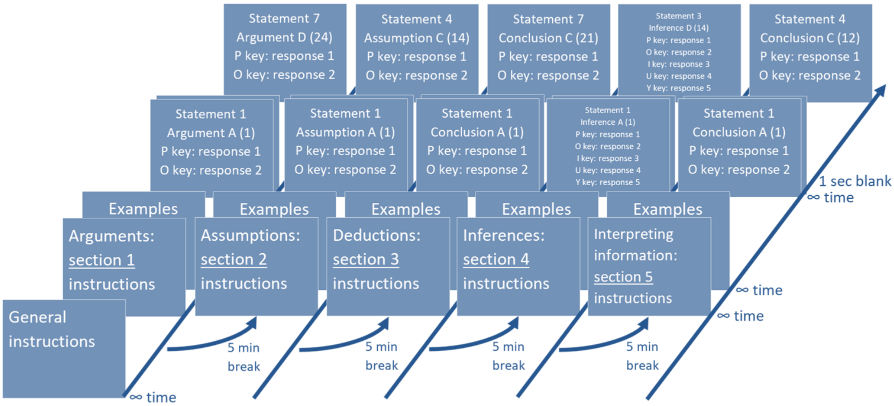

Figure 1. Design of the critical thinking task. The first and the last questions of each section are shown. Parentheses indicate the number of questions within a section, e.g., section 4 had 14 questions.

2.5. Signal Analysis

2.5.1. EEG Pre-processing

EEG data were pre-processed using MATLAB and EEGLAB toolbox (v2021.0). Signals were channel-locked, baseline-removed, and noise-cleaned using CleanLine (Mitra & Bokil, 2007). Clean_rawdata (Kothe & Makeig, 2013) removed significant amplitude artifacts. A high-pass Butterworth filter at 1 Hz, and independent component analysis (WICA plugin) were applied to identify and remove sources such as cardiac, muscular, and ocular activity.

2.5.2. Event-Related Potentials (ERPs)

Epochs were extracted in line with correct and incorrect responses (-300 to 1000 ms), and question presentations (-300 to 2000 ms). Then, ERPs were plotted for the three study cases.

2.6. Statistical Analysis

2.6.1. Event-related Responses: Correct and Incorrect

Correct vs. incorrect responses were analysed using paired t-tests and one-way ANOVA, supplemented by nonparametric permutation testing (10,000 iterations) to address parametric assumptions. Condition labels were shuffled while preserving data structure to create empirical null distributions. After pFDR correction (Storey, 2002), neither parametric nor permutation tests revealed significant differences.

2.6.2. Event-related Questions

One-way ANOVA was applied to compare the five sections of the critical thinking test. The results showed no significant differences, consistent with prior research on averaging limitations (Van Vliet et al., 2016; Lee et al., 2016).

3. Results

3.1. Scores critical thinking task

The mean and standard deviation of scores in each critical thinking task section from all participants are shown in Table 1. As the standard deviation is small, most of the participants were consistent in their answers.

3.2. Event-related Responses: Correct and Incorrect

A negative component with 200 ms latency (N200) after the responses of participants is shown in Figure 2. A positive component with 275ms latency (P275) was also present. P275 had the highest peak mean amplitude in frontal pole channels and the longest latency to return to baseline. Sample-wise t-tests with pFDR correction did not find a statistically significant difference between correct and incorrect components on the mean amplitudes at timepoints near their peaks. All other timepoints' t-tests from this comparison were also not statistically significant after pFDR correction.

Analysis based on event-related responses (correct and incorrect) across the five sessions showed the same components and similar distribution across channels. Sample-wise, one-way ANOVAs with pFDR correction did not find a statistically significant difference between section-specific.

Table 1: Mean ($\bar{x}$) and standard deviation (SD) of proportion scores in each critical thinking task section from all participants.

	Sample (n=18)
Scores in section 1: $\bar{x} \pm SD$	0.6250 ± 0.1178
Scores in section 2: $\bar{x} \pm SD$	0.6008 ± 0.1096
Scores in section 3: $\bar{x} \pm SD$	0.7255 ± 0.1061
Scores in section 4: $\bar{x} \pm SD$	0.4127 ± 0.1134
Scores in section 5: $\bar{x} \pm SD$	0.6852 ± 0.0836

3.3. Event-related questions

Results showed in Figure 3 several local minima (hereafter denoted with N) and maxima (hereafter denoted with P) in these ERPs. About 12 components could be identified (N100, P125, N150, P155, N175, P225, N280, P280, N325, P375, N425, and P1050). ERPs from question presentations were also divided by section. Sample-wise, one-way ANOVAs with pFDR correction did not find a statistically significant difference between section-specific, question presentation ERPs on the mean amplitudes at timepoints near the peaks of all previous components. All other timepoints' one-way ANOVAs from this comparison were also not statistically significant after pFDR correction.

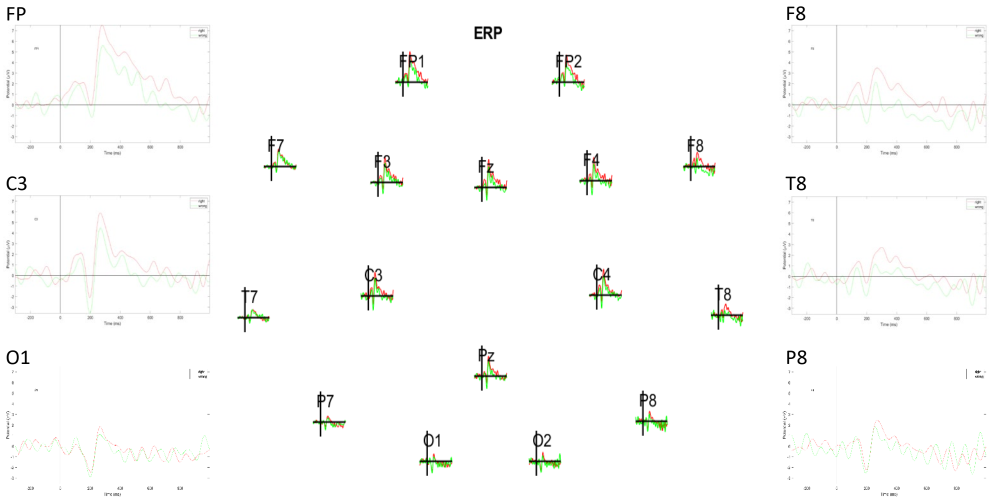

Figure 2: ERPs from all right and wrong responses of the critical thinking task. Red = right, green = wrong. X-axis: vertical line = 0ms, label intervals = 200ms, limits = -300 to 1000ms. Y-axis: horizontal line = 0µV, label intervals = 1µV, limits = -3.5 to 7.5µV.

4. Discussion

This study investigated the neural underpinnings of critical thinking as a transversal competency in undergraduate students by analysing their event-related responses (both correct and incorrect ones) and event-related questions. Two primary ERP components, N200 and P275, were identified, corresponding to Error-Related Negativity (ERN) and Positivity (PE), respectively, as described in the literature (Dietrich, 2004; Hughes & Zaki, 2015; Falkenstein et al., 1991). However, the analysis revealed no statistically significant differences between correct and incorrect responses, suggesting that mental resources employed in both processes are very similar, at least being analysed by ERP techniques.

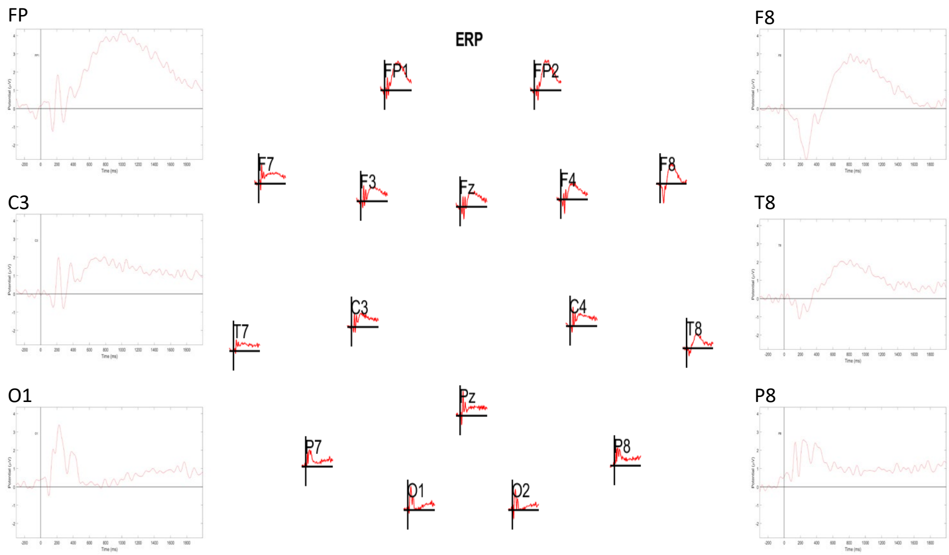

Figure 3: ERPs from all question presentations in the critical thinking task. X-axis: vertical line = 0ms, label intervals = 200ms, limits = -300 to 2000ms. Y-axis: horizontal line = 0µV, label intervals = 1µV, limits = -2.75 to 4.25µV.

The presence of twelve identifiable components during question presentations, including N100, P125, and P275, highlights the complexity of cognitive processing during critical thinking tasks (Luck, 2014). Nonetheless, the absence of statistically significant differences between subtests or conditions underscores the need for further studies to elucidate the relationship between neural activity and critical thinking performance. The high variability in cognitive engagement across tasks and the relatively small sample size likely contributed to this limitation (Cohen, 1992). It is recommended to perform an Inter-Trial-Coherence analysis for differentiating between components and peaks. Possibly, some of the twelve appearing components are only peaks, and they could be only fortuity events, rather than cognitive processes.

The findings of this study align with prior work suggesting that critical thinking is a multifaceted cognitive process, engaging diverse neural networks without clear differentiation by task accuracy (Goel et al., 2017; Thagard, 2011; Holroyd et al., 2008). The results extend this understanding by demonstrating the feasibility of using real-time EEG to investigate critical thinking. However, the findings emphasize the importance of refining methodological approaches, including larger samples and more targeted task designs, to capture the nuanced neural mechanisms underlying this skill. A further study with more focus on the evaluation of the critical thinking test is suggested. For example, reaction time to read and answer the questions could be a dependent variable to reorganize epochs and visualize different components, or different ERP properties. The study's findings have several implications for education and future research, i.e. If neural engagement in correct and incorrect critical thinking processes is indeed similar, educators might focus on metacognitive training to help students better monitor and adjust their reasoning strategies, rather than solely emphasizing accuracy. And for assessment methods, incorporating neurophysiological measures (e.g., EEG) alongside traditional assessments could provide a more holistic understanding of students' critical thinking development.

5. Conclusion

This research contributes to the development of neuroeducation by identifying neurophysiological markers of critical thinking. Although the study did not find conclusive evidence of differences in neural activity between correct and incorrect responses, the identified ERP components provide a foundation for future research.

Future studies should address the limitations noted here by employing more robust statistical analyses, increasing sample size, and exploring longitudinal designs to understand how critical thinking develops over time (Button et al., 2013). Additionally, integrating multimodal approaches, such as functional MRI and behavioral data, could offer richer insights into the cognitive and neural dimensions of transversal competencies (Wertheim & Ragni, 2020; Van Vliet et al., 2016).

Finally, the integration of neuroscientific findings into educational frameworks holds promise for enhancing the evaluation and development of critical thinking, equipping students to navigate the demands of a complex, rapidly evolving world (Alsina et al., 2011; Sarathy, 2018).

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