Peer-Reviewed Structured Abstract

The Effect of Prior Programming Knowledge on Memory Efficiency When Learning a New Language

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Summary

Learning computer programming is a demanding cognitive task that requires a number of competencies. Students with limited problem-solving skills or prior programming knowledge find it challenging to understand the abstract concepts involved.

While much research has investigated how cognitive load affects learning, few studies have explored the effect of prior programming knowledge on cognitive load and memory efficiency. This research uses the EEG data, modelled in the NeuCube spiking neural network architecture, to analyse the memory efficiency in two groups of students, with and without prior programming knowledge, when learning a new language. Based on the quantitative analysis of brain neuronal connectivity captured in the NeuCube models, it is concluded that prior programming knowledge results in less cognitive load, meaning more efficient memory use. Findings and results of empirical data analysis in this study can inform educators to develop strategies and design personalised learning interventions based on the student's prior knowledge.

Background

Programming has become an essential skill in today's digital world, integral to the education, training, and IT sectors. However, mastering programming is a complex cognitive task, requiring learners to understand logic, syntax, and semantics, which places significant cognitive demands on them [1]. This complexity is particularly challenging for students with limited problem-solving abilities or prior knowledge, as they often struggle with the abstract concepts inherent in programming [2].

Few studies have investigated the cognitive load in memory associated with programming tasks, particularly through objective measures like electroencephalogram (EEG) data [3,4]. This study addresses the gap by exploring the effect of prior programming knowledge on memory efficiency when learning a new programming language.

Due to the dynamic nature of the EEG data, their analysis is complex. Brain-inspired computational models, particularly spiking neural networks (SNNs), are suitable for time-series data analysis, as they mimic the brain's biological neural processes. SNNs follow the same computational principle in the brain for neuronal communication, known as spike information processing [5]. The importance of this research lies in its results and findings confirming the specific neuronal patterns with respect to prior programming knowledge and memory using an SNN approach. In addition, the findings can guide educators in developing effective educational strategies and designing personalised interventions that align with the student's prior knowledge.

Methodology

Data were collected from 21 male and 5 female students who were about to start their programming course at university. Participants were categorised into two groups based on their performance in 17 programming comprehension tasks. The tasks required participants to review C programming language code snippets and select the correct output from four choices. Participants' scores ranged between 2 and 11. The median of the scores (7) was used as the threshold for the group formation. Fourteen participants who scored seven or below were placed into the insufficient prior knowledge (IPK) group. Twelve participants who scored above seven were placed into the sufficient prior knowledge (SPK).

EEG data were collected using the 14-channel Emotiv Epoch X device and analysed using the NeuCube SNN-based architecture [7]. The analysis focused on the brain's left frontal and temporal lobes, corresponding to EEG channels F7 and T7. Previous research identified these regions as highly active during programming tasks [6].

Feature extraction was performed using MATLAB's Fast Fourier Transform (FFT) method, resulting in six spectral features(wavebands): Delta, Theta, Alpha, Beta High, Beta Low, and Gamma. The data were then organised into samples with ordered time points for each spectral feature.

Results and Observations

Two analyses were performed on the data extracted from channel F7 (left frontal lobe) and T7(left temporal lobe) to explore the neuronal activity patterns in the Theta and Alpha wavebands with respect to memory efficiency in the IPK and SPK groups. Previous research showed that reduced cognitive load is associated with reduced Theta and increased Alpha [6].

The organised samples underwent encoding, initialisation, and unsupervised learning processes. Two models were built, one for each of the two groups (SPK and IPK). Neuronal interactions were quantified by computing the proportion of neurons associated with each frequency band relative to the total number of neurons in the SNN cube [7]. Focusing on the Theta and Alpha wavebands, these neuronal proportions were averaged per group.

The analysis of F7 data revealed that the IPK group experienced higher cognitive load, indicated by increased Theta activity (17.05%) and decreased Alpha activity (16.16%). In contrast, the SPK group showed lower cognitive load with decreased Theta (11.58%) and increased Alpha (17.58%). The results confirmed the pattern found in the previous study, indicating that prior programming knowledge reduces cognitive load. The participants' performance scores also aligned with the result, suggesting that a lower cognitive load facilitate efficient memory use.

The T7 analysis showed reduced Theta (13.30%) and increased Alpha (14.84%) activity, indicating reduced cognitive load in the SPK group. Similarly, the IPK group also showed a reduction in Theta (13.78%) and a rise in Alpha (16.5%). Although this activity did not follow the higher Theta and lower Alpha pattern for increased cognitive load expected in the IPK group, comparing the averaged neuronal proportion between the two groups still showed higher neuronal activity in the IPK group, suggesting they experienced a higher cognitive load.

A previous study linked increased Theta activity to greater cognitive control and task complexity, with Alpha activity reflecting cognitive readiness and attention management [8], supporting our findings in F7. The inconsistency in T7 channel activity reflecting the IPK group may be related to the temporal lobe's sensitivity to emotional and contextual factors [9] and individual differences in Alpha frequencies [10].

Conclusion

This study demonstrated a clear pattern of neuronal activity, marked by reduced neuronal activity in the Theta waveband and increased activity in the Alpha waveband, particularly in the SPK group in both the left frontal and temporal lobes. These findings indicate that having prior programming knowledge affects the efficient use of memory and highlights the important role of foundational knowledge in learning computer programming. The application of NeuCube also underscored the use of SNN-based computational models in educational research. This research is part of a larger project investigating the transfer of learning processes (including memory efficiency) using cognitive computation.

Acknowledgement

The NeuCube spiking neural network software, developed at KEDRI/AUT in MATLAB and Python languages, is available from https://kedri.aut.ac.nz/neucube.

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