Cognitive Conflict in Virtual Reality Based Object Selection Task

An EEG study to understand brain dynamics associated with cognitive conflict in a Virtual Reality 3D object selection task

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Certificate of Authorship/Originality

I, **Avinash Kumar Singh** declare that this thesis, is submitted in fulfilment of the requirements for the award of Ph.D. degree, in the School of Software, Faculty of Engineering and Information Technology at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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(Avinash Kumar Singh)

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Journal papers

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List of Abbreviations

2D	Two-dimensional
3D	Three-dimensional
ACC	Anterior Cingulate Cortex
ADJUST	Automatic EEG artifact Detection based on the Joint Use of Spatial and Temporal feature
ANCOVA	Analysis of Co-variance
ANN	Artificial Neural Network
ANOVA	Analysis of Variance
AR	Augmented Reality
BAS	Behavioral Activation System
BACh	Brain Automated Chorales
BCI	Brain-Computer Interface
BIS	Behavioral Inhibition System
BSS	Blind Source Separation
DAL	Dual-augmented Lagrange
DIPFIT	Dipole Fitting
EEG	Electroencephalogram
EMS	Electric muscle stimulation
ERN	Error-Related Negativity
ERP	Event-Related Potential
ERSP	Event-Related Spectral Perturbation
FFNN	Feed-forward Neural Network
FIR	Finite Impulse response
fMRI	Functional Magnetic Resonance Imaging
fNIRS	Functional Near-Infrared Spectroscopy
FPS	Frame per Second
FRN	Feedback-Related Negativity
GMM	Gaussian Mixture Modelling
GSR	Galvanic Skin Response
HCI	Human-Computer interface
HMD	Head Mounted Display
IC	Independent Component

ICA	Independent Component Analysis
ID	Index of Difficulty
IMU	Inertial Measurement Unit
IPQ	Igroup Presence Questionnaire
IQR	Inter-Quartile Range
ITC	Inter-Trial Coherence
LDA	Linear Discriminant Analysis
MMN	Mismatch Negativity
MoBI	Mobile Brain / Body Imaging
MR	Magnetic Resonance
N2	Negativity at 200ms
Ne	Negativity
OCD	Obsessive-Compulsive Disorder
oFRN	Observational Feedback-Related Negativity
OLED	Organic Light-Emitting Diode
P300	Positivity at 300ms
PCC	Posterior Cingulate Cortex
Pe	Positivity
PEN	Prediction Error Negativity
PET	Positron Emission Tomography
pre-SMA	pre-Supplementary Motor Area
QDA	Quadratic Discriminate Analysis
SASICA	Semi-Automatic Selection of Independent Components for Artifact
SCCN	Swartz Center for Computational Neuroscience
SD	Standard Deviation
SDK	Software Development Kit
SFG	Superior Frontal Gyrus
SNR	Signal-to-Noise Ratio
SVM	Support Vector Machine
TV	Television
UAV	Unmanned Aerial Vehicle
VE	Virtual Elements
VR	Virtual Reality

Abstract

Cognitive conflict is an essential part of everyday interaction with the environment and is often characterized as a brain's action monitoring and control system that activates when prediction based on previous experience acquired from the environment does not match with derived knowledge from sensory inputs from cognitive processing. Although cognitive conflict can be seen as an essential part of learning about the environment, it requires the brain to assign a higher number of cognitive resources such as attention, memory, and engagement compared to non-conflicting conditions. In this work, cognitive conflict has been evaluated in a three-dimensional (3D) object selection task in a virtual reality environment by assessing, evaluating, and understanding the factors of visual appearance, task completion time, movement velocity during interaction and its implications for a sense of agency, and presence in a virtual reality (VR) environment. An electroencephalogram (EEG)-based approach along with behavioral information is used. The results show that the amplitude of negative event-related potential (50-150 ms), defined as prediction error negativity (PEN), correlates with the realism of the rendering style of virtual hands during the interaction. It was also found that PEN amplitudes are significantly more pronounced in slow trials than fast trials. Based on these findings, a closed-loop BCI system has been designed to assess the effect of cognitive conflict in 3D object selection and provide the matrices which can improve users' feelings of a sense of agency towards VR. These findings suggest that a realistic representation of the user's hand, compatible task completion time and hand movement velocity are essential components for the better integration of information from both visual and proprioceptive systems during the interaction to avoid cognitive conflict due to a mismatch between action and expected feedback. The findings also suggest that the assessment of cognitive conflict measured by PEN can improve the overall experience of the 3D object selection task in a VR environment. Collectively, these findings provide a glimpse of understanding into how the brain dynamics behind interaction works and its implications in assessment for the content development industries in VR.