

**DEVELOPMENT OF COGNITIVE SKILLS ENHANCEMENT
MODEL FOR SPORTS PERSONS**

A

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CERTIFICATE

I, **Ashish Aggarwal** hereby certify that the work presented in this thesis report entitled “**Development of Cognitive Skills Enhancement Model for Sports Persons**” in fulfilment of the requirements for the award of the degree of **Doctor of Philosophy** and submitted in Electrical and Instrumentation Engineering Department of Thapar Institute of Engineering & Technology, Patiala, is an authentic record of my own research work under the supervision of **Dr. Ravinder Agarwal**, Professor, Electrical and Instrumentation Engineering Department of Thapar Institute of Engineering & Technology, Patiala.

The matter presented in this thesis has not been submitted by me for the award of any other degree or any other Institute.


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SUMMARY

The elite-level performance in sports requires the optimal functioning of cognitive skills such as attention and working memory in complex dynamic environments. Players need to extract and integrate meaningful information while allocating the attentional resources of the brain in different areas of dynamic scenes. Several factors, such as background noise, the field of view, and the number of players (opponents and teammates) affect the functioning of cognitive skills in the field. Computerized cognitive training is one of the methods meant to enhance cognitive skills. Psychological measurement is a well-recognized way of assessing cognitive skills. The brain is the seat of all cognitive processes and measured through brain signals, *i.e.*, Electroencephalograph (EEG). The non-invasive nature of EEG signals made it promising to acquire neural information about cognitive skills.

The prime objective of the present research work is to design a cognitive training model and provide psycho-physiological evidence of enhancement in cognitive skills. Here, a cognitive training model, Multiple Object Tracking (MOT) was designed, which incorporates the factors; background noise, the field of view, and several subjects, which affect cognitive skills. EEG signals from 14-channels using Emotiv Epoc of twenty-five football players were recorded while performing MOT. Several artifacts like muscles, powerline, eye blink artifacts, *etc.* affect the analysis of the brain signals. The combination of independent component analysis and wavelet transform was used to denoise the signals. The efficacy of the denoising process was evaluated by adding the artificial noise in the clean signal and again denoising using the same process. The selection of the wavelet was crucial to denoise and decomposed the EEG signals. The process of EEG signal denoising was repeated using 109 types of wavelets from daubechies, symlets, coiflets, haar, dmeyer, biorthogonal, and reverse biorthogonal families. The performance of 'bior3.1' of the biorthogonal family outperformed and identified as optimal wavelet for the processes of denoising and decomposition.

Thereafter, it was important to identify the most activated brain area in a cognitive task, which demands high cognitive skills. Four levels of MOT task with varying cognitive load were designed. The cognitive load varied in terms of the number of targets from 2 to 5 among the 6 distractors in four levels (L1 to L4), respectively. The performance of the participants was a decline with the cognitive load. The frontal region of the cortex was identified as the most

activated area while performing the MOT task. Further, the relationship between alpha, beta, and theta waves with cognitive load was assessed for individual cognitive capacity. Participants were divided into three groups (high, medium, and low performers) based on d2 test results using the ward method. The increase in theta, decrease in alpha and beta activities was observed with an increase in cognitive load and the high performer group showed good cognitive capacity.

Thereafter, the efficacy of cognitive training was evaluated. Three times the psycho-physiological measurement of the cognitive skills were performed; pre, post, and post2. The pre-measurement was performed before the starting of the cognitive training. Thereafter, the post-measurement was performed at the end of cognitive training. Players need to continuously maintain a high level of cognitive skills. Therefore, to investigate the longevity effect of cognitive training, post2 measurement was performed after the three months of the post measurement. Three groups of participants were selected for the experimentation; active group (players, training group), passive group (players, non-training group), and control group (non-athletes). The psych-physiological measurement was performed before the training. Six psychological tests (Corsi, digit span, two-back for working memory and stroop, identification, continuous performance test for attention) were used to test the cognitive skills. EEG signals were also recorded while playing the MOT task. The cognitive skills were examined using EEG sub-frequency bands, alpha, beta, and theta. The power spectral density and partial directed coherence (a measure of brain connectivity) were assessed to evaluate the training efficacy. It was identified that players had better cognitive skills than non-players. Then, cognitive training was given to the active group for four weeks (20 sessions). Post measurement was performed after the completion of training. The comparative analysis of pre and post-measurement showed significant improvement in the cognitive skills of the active group, while no changes observed in other groups. The comparison of the pre and post-measurement showed a decrease in theta, increase in alpha and beta activity. Working memory and attention cognitive functions are associated with the enhancement in beta and alpha. It suggested that cognitive training increased cognitive capacity. Also, the synchronization in alpha and beta is associated with the decreasing effect of background noise, the field of view, and several subjects. The desynchronization of theta revealed that the player's capacity to accommodate a high cognitive load is increased. The results of psychological tests are in support of the results of physiological measurement. The post2 measurement is performed to evaluate the longevity after the three months. A significant decline is seen in the cognitive skills of the active

group. Thus, it was concluded that cognitive training effectively enhanced the cognitive skills and also, reduced the effects of the disturbing factors. The effect of cognitive training is time-limited and declines with time.

In the end, four psychological tests (one-beep, two-beep, left-right, and visual search tests) were designed to evaluate the effect of cognitive training on the audio-visual stimuli and visual search field. One-beep and two-beep tests evaluate the cognitive capacity in the audio stimuli, whereas the other tests used the visual stimuli with divided attention. Two groups of participants were selected for the experimentation; active group (training group) and passive group (non-training group) and performed the four cognitive tests. Then, cognitive training was given to the active group (20 sessions) and post-measurement was performed after the training. The active group showed significant changes between the pre and post-measurement, whereas insignificant changes were observed for the passive group. The results indicated that the cognitive training enhanced the cognitive skills and performance in the cognitive tests. It was concluded that cognitive training helped the participants to reduce the effect of audio and visual interference on their performance.

LIST OF ABBREVIATIONS

Approximation Coefficients	cA
Average Performance Accuracy	%APA
Continuous Performance Test	CPT
Corsi Block Tapping	CBT
Detailed Coefficients	cD
Digit Span	Dspan
Discrete Wavelet Transform	DWT
Electroencephalograph	EEG
Heart Rate Variability	HRV
Identification	IDN
Independent Component Analysis	ICA
Multiple Object Tracking	MOT
Neurofeedback Training	NFT
Partial Directed Coherence	PDC
Percentage Relative PSD	%RPSD
Power Spectral Density	PSD
Psychology Experiment Building Language	PEBL
Root Mean Square	RMS
Sport Competition Anxiety Test	SCAT
Support Vector Machine	SVM
Two Back	TWOB

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Chapter 1

Introduction

1.1 Cognition

Cognition has a long history dating back to the ancient Greeks. Neisser given the most influential definitions of cognition: It refers to all the processes by which the sensory input is transformed, reduced, elaborated, stored, recovered, and used [1]. There are two influential aspects of cognition, *i.e.*, information processing and dynamic process. It is a mental perspective as the minds acquired the information from the environment and continuous process and stored the information [2,3]. Cognition is akin to a physical mechanism that consists of parts and operations in which one part operates on another part. It benefits from the conceptual, theoretical, and empirical knowledge that psychologists have gathered about how the environment influences behavior. The knowledge about the relationship between environment and behavior will make us understand the cognitive state.

Cognition describes all the necessary skills necessary for successful functioning in everyday life. It is alluding to the procedures associated with picking up information from the environment. These procedures incorporate reasoning, knowing, recollecting, judging, and critical thinking. The most important cognitive elements of the mind are attention and working memory. Cognitive processes use these cognitive elements to utilize existing information and yield new learning. In daily life, these cognitive processes are required to integrate information from various sources like objects, motion, speed, locations, *etc.* For example, people must practice rapid/slow movement to avoid collisions while walking down a busy street, or at a crowded shop. It requires an evaluation of traffic and pedestrian movement during crossing a road while maintaining a navigational goal. The information available in our visual field must be integrated for an effective outcome [4].

The cognitive ability helps to collect and efficiently process spatial-temporal information. It makes us understand information about the world and interact safely with the environment. The successful integration of cognition processes controls our thoughts and behaviors, which are regulated by brain circuits. These processes are multisensory and particularly very complex. All the cognitive processes held in the brain and affect neural information processing. Cognitive

processes are the software of the mind and can be studied using a computer system. To understand the mental algorithms involved in cognitive processes, it is important to analyze the nature of the input, process, and output of the data. Thus, cognition helps to recognize features of the world in the brain. In a nutshell, cognition covers the mental functions, mental developments, and state of intelligent entities.

1.2 Cognition in Sports

Cognition plays a vital role in understanding, predicting, and potentially improving sports performance [5,6]. The high level of cognition develops a higher ability in players to execute the cognitive processes [7,8]. Cognitive capacity makes the players able to predict and acquire visual cues in the sporting environment [9]. The integration of information helps players to perform faster, more effectively, and accurately on sport-specific cognitive tasks.

The Player's every action includes cognitive skills to analyze all stimuli. In strategic sports, like football, the decisions are naturalistic and dynamic, which are influenced by the field of view, audience noise, limited time, various intensities of exercise, limited resources to acquire information, and under pressure situations [10]. These processes are very complex and required high-level skills for effective outcomes in the field. Each player will approach a situation in their ways and rely on a combination of experience, physical, and cognitive skills [11]. The domain-specific cognitive mechanisms enable the players to anticipate and correctly predict the situations in a dynamic environment [12]. Cognitive ability is a crucial asset of players, which helps to understand and process the knowledge.

The most challenging task for an athlete on the field is to observe and integrate complex moving patterns while distributing attentional resources in key areas of the dynamic scene. Players need to pay attention to several members of the opposition as well as key teammates during critical phases of play [13]. In football, a defender needs to block the opposition attacker in possession of the ball. The defending player must anticipate the attacker's strategy by perceiving opportunities for oncoming movement into free space, judging distances between oneself and other defenders, passing to self-team attackers, and determining the teammates intercepting points. The movements of the players and the object of play abruptly change with time and situations. It is difficult to predict the locations of these elements with dynamic changes in speed, direction, and occlusions, such as players blocking the view of others. Expert players are better

than a novice in mental tasks and performed effectively. Elite players make perceptions that are based on moment-by-moment tracking, especially as attacking play will regularly involve efforts to move along unpredictable paths. The combination of factors affecting the functioning of cognitive skills in complex situations is the determining aspect to perform at superior levels. Cognition improves the ability of athletes to perceive and react to several stimuli in competitive sports [14–16]. Expert athletes are proficient in anticipation of opponent actions, pattern recall, and strategic awareness. Thus, high-level cognitive capacity is very necessary to acquire the visual cues and knowledge of the situation probabilities.

1.3 Cognitive Skills

Cognitive skill is defined as the ability of an individual to locate, identify, and integrate environmental information with existing knowledge. Cognitive skills underpinning performance include more efficient and effective use of vision to extract relevant information from the environment [17,18]. Players should have expertise in sports-related tasks, including superior vision capacity, pattern recall, and recognition with knowledge of dynamic situations [11]. These approaches help the players to recognize the other athlete's actions and make correct decisions for the execution of their actions effectively. The execution of vision-based processes required high-level cognitive skills, like attention and working memory. In the field, athletes need to divide attention into several components, *e.g.*, opponents, ball, teammate, *etc.* Simultaneously, it is required to store the relevant information in the memory and filter out the irrelevant information. Some of the key components to be considered while assessing the cognitive ability are;

a) Attention

Attention is the behavioral and cognitive process of selectively concentrating on an imperative aspect of information while ignoring other extraneous information. Attention has been mentioned as the distribution of processing resources. The athlete should have a high attentional capability to coordinate the necessary factors for optimal performance. Players must exhibit higher attentional flexibility to modulate specific resources according to task demands. Several tasks can be considered to measure this cognitive ability [19,20]. A simple example can be a mathematical problem that draws a lot of attention to the human brain. An individual is asked to recall several digits after the digits are shown to a participant for a short duration of time.

Attention is a basic requirement for being able to perform other elements of the cognitive assessment.

b) Working memory

Working memory is the ability to actively maintain and use representations for ongoing processing and recall after a small period. A healthy adult can store up to 3–4 items at a time, and this capacity varies considerably across individuals [20,21]. It plays a significant role in higher cognitive functioning, such as thinking, planning, reasoning, and decision making. It is a neural mnemonic system that processes and temporarily stores information required for complex cognitive activities. It is a vital component of decision-making and cognitive functioning under high demanding conditions [14]. If available information is not enough to make a decision, then the player's prior stored knowledge assist in the interpretation of a situation. Thus, the neuronal mechanisms that are utilized in working memory provide relevant information on cognitive functioning.

c) Reaction time

Reaction Time is the minimum time from the presentation of a stimulus, to identify relevant cues, process the information, and respond to the stimulus [20]. The accuracy of the responses is affected by the specificity of the task. The Player's reaction time in rapidly changing environments depends on the information available in the field. The player needs to filter out the relevant information to respond fast and accurately. Speed and accuracy are the desired elements to implement the decisions. Players' attentional capability helps to locate the specific visual cues while working memory store and process the information. Draheim *et al.* [22] and Prinz *meta et al.* [23] describe the relationship of reaction time with attention and working memory. Attention and working memory are the key cognitive skills that help the players respond at high speed.

d) Motor speed

Motor speed is the ability of an individual to coordinate hand-eye movements and maintain balance during the tasks effectively. It is described as the player's capacity to respond as fast as possible and perform movements with the highest speed in sport-specific conditions. Physical exercises improve the motor timing of the players. Although, attention and working memory are the key cognitive skills that significantly affect its variability and accuracy [24,25].

1.4 Cognitive Skill Enhancement Training

Cognitive training is a program of regular activities purported to maintain or improve cognitive skills. This process refers to enhancing components of fluid intelligence, such as attention and working memory, by exercising the brain. Our brain has the potential to adapt and to develop new abilities throughout our lifetime [21]. Thus, cognitive training is defined as the science of neuroplasticity, which makes the brain able to recognize and create new pathways. Researchers have shown that cognitive training underlying brain coach results in the improvement of several cognitive skills, including attention, decision making, working memory *etc.* [26,27].

The player needs to perceive and integrate the information in a dynamic visual field to involve cognitive skills. It is well accepted that expert performance in sports highly depends upon high-level cognitive skills. The wealth of cognitive skills helps the players to perform at optimal levels in stressful and demanding environments [6]. Cognitive training is a highly researched method of enhancing cognitive skills through repetitive and targeted exercise. A player should have high cognitive ability, but the execution of cognitive skills may be situation-specific with things such as lack of concentration, fear and anxiety, and arousal level [27]. The functioning of cognitive skills is also influenced by background noise, the field of view, and the number of players (opponents and teammates, nearby or far away) [11,13,28]. Thus, actively training cognitive skills under different task conditions is an important consideration in the training and development of players.

Cognitive enhancement refers to any improvement in cognitive performance following targeted interventions. Cognitive training is a rapidly growing market with the potential to expand in the future [4]. Further, Several training programs promoting cognitive skills enhancement have been developed in recent years [29]. Within the research field, advances have been made regarding our understanding of the benefits inherent to cognitive programs, mainly involving working memory and attention training programs. In distinct literature, physical exercise and computerized training have been shown to broadly enhance the cognitive functions of athletes [26,30,31]. Computerized cognitive training is a flourishing field within the scope of cognitive enhancement, with applications being studied extensively in many different cohorts. Thus, the target of the present research work is to develop a cognitive training model with consideration of factors affecting cognitive skills.

1.5 Electroencephalograph and Cognitive Skill

An electroencephalograph (EEG) signal refers to the recording of the electrical movement of the brain activity over a time frame. The neurons of the human mind process data by changing the stream of electrical ebbs and flows over the membrane. These changing streams produce electric fields that are recorded by putting electrodes on the scalp according to the 10-20 system (Figure 1.1). The potentials between various electrodes are amplified and recorded as the EEG, which implies the composition out of the electrical movement of the cerebrum [32,33]. Spectral analysis is used to decompose the EEG signal into sub-frequency bands which are categorized as delta (0.5-4 Hz), theta (4-8 Hz), alpha (8-12 Hz), beta (12-30 Hz), and gamma (>30 Hz).

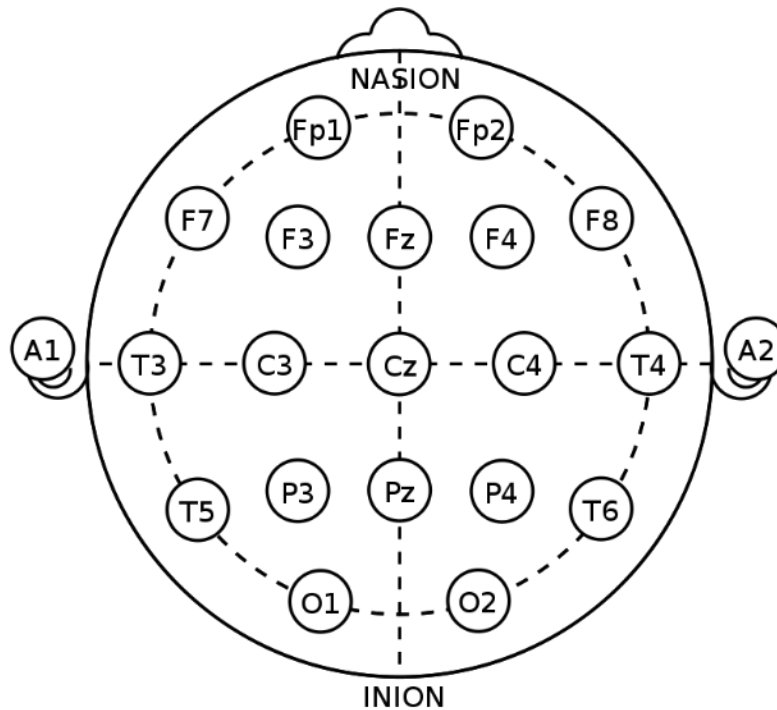


Figure 1.1 10-20 system of electrode placement

EEG contributes to the research community for the assessment of changes in the real-time brain dynamics to provides an opportunity to explore the relationship between brain activities and cognitive skills. Several studies demonstrated a pronounced role of theta, alpha, and beta frequency bands in the effect of cognitive training [34,35]. Given the role of EEG sub-frequency bands in comparing the pre and post-measurement of cognitive training, it is also found to be correlated with efficient cognitive skill performance. Attention and working memory share the same region of the cortex [36,37]. Beta oscillation is related to attention and helps to be

dominant in a task. Alpha is the dominant wave of the EEG and associated with a state of relaxation, working memory, and cognitive workload. Alpha is associated with the suppression of irrelevant information in working memory tasks. Theta frequency is associated with memory functions and cognitive workload.

1.6 Objectives of the Present Research Work

The objective of the present research work is to develop a cognitive training model considering the factors affecting cognitive skills. The following objectives of the thesis are formulated to understand the aspects of cognitive training on brain waves (EEG) along with psychological tests.

1. To study the existing models, their drawbacks, and strengths in the light of cognitive skills, *e.g.*, reaction time, attention, motor speed, working memory.
2. Develop a cognitive training model to improve the cognitive skill's efficiency of sports players
3. Interpret differences between pre and post-test measurements of physio-psychological parameters.

1.7 Thesis Overview

The present thesis consists of six chapters, organized as follows:

In this chapter, a brief introduction of cognition, the importance of cognition in sports, cognitive skills, and cognitive skill enhancement training is described. Also, the relationship between electrophysiological signals and cognitive skills is described.

Chapter 2 includes an overview of the literature which tries to elucidate the research gap in the previous studies. In this chapter, cognitive skills enhancement methods with the assistance of strengths and limitations have been explained. Also, psycho-physiological methods to assess the effects of cognitive training on cognitive skills are described.

Chapter 3 deals with the methodology in detail involving specified materials, methods, and procedures for the experiment. This chapter also explains the techniques used to analyze the results of the particular experiment.

Chapter 4 embraces the results and discussion part to demonstrate the signal and statistical processing of the variables obtained through the experimentation. The systematic explanations are also given for the obtained results and the proposed hypothesis in particular experimentation.

Chapter 5 covers the design of cognitive tests for the validation of the cognitive training effects. It describes the experimental method used to measure cognitive capacity in audio-visual stimuli and presents the results of the cognitive training.

Chapter 6 concludes the research work of the thesis and future scope.

Chapter 2

Literature Review

2.1 Cognitive Training

The search for high performance in sport is the leitmotif of any player. Physical preparations, nutrition, and technical training are necessary steps to improve the performance of athletes. Sports science is going towards the enhancement of cognitive skills to boost cognitive ability which improves the performance in sports. It is supported by a recent scientific study revealing that cognitive skills are linked to the success of elite football players [9]. The results from this study suggest that cognitive function tests predict the success of ball sport players. High-level cognitive skills are crucial for the talent identification and development of young football players [14]. The findings show that the highly talented soccer player group has superior motor inhibition capability in the attention network test as compared to the armature group. Researchers have explored the plastic capacity of the brain in laboratory-based training and enhanced the cognitive learning of athletes[31]. These techniques are getting significant recognition from coaches in sports programs [38].In this study, integrated psychological and biofeedback training is provided to the athletes and constructive output is observed at the field.

The basis of the cognitive processes is the adaptive development of the whole human's neural networks [39]. Our brain can compensate for the effects generated by the intrinsic and extrinsic factors by restructuring neural networks[40]. The results show that it is very active during postnatal (0-16 years) development. There is an apparent reorganization of the neural networks in learning new abilities[41] andfound that its capacity significantly decreases with the difficulty of the task and cognitive load.

In the acquisition of the experience, the capacity of the synaptic plasticity of the brain plays a crucial role in the restoration of affected function following a brain injury [42,43]. Brain plasticity is induced during cognitive learning[44], which results in performance changes following training. Thus, cognitive learning is defined as an increase in the ability to extract information from the environment resulting from repetitive exercises.

Cognitive training programs are designed in the laboratory to improve cognitive skills in young and older adults [45]. The results showed that participants eliminated the difference in biological motion perception between 4m and 16m. Cognitive training also helps to improve the cognitive skills of athletes [13,31] and the results show the enhancement in-field performance. There are many techniques and laboratory-based cognitive training models to enhance the athlete's cognitive skills. The laboratory-based training models should have robust transfer effects, no side effects, cost-effective, lasting effects, no ethical problem, and applicable to any individual [34]. Apart from the aforementioned characteristics, the cognitive training model should incorporate other factors that affect the working of cognitive skills in the field like background noise, the field of view, *etc.* [13,46]. In this study, a cognitive training model is designed which incorporates the above factors. However, it is important to discuss the research related to previous cognitive training methods.

Cognitive training research started in the early 1950s when Damron trained two groups of football players using slide presentations [47]. Players participated in 16 sessions of slide presentations and were able to recognize 75% of the football-specific situations accurately. The results of this study suggested that cognitive skills are trainable. It was also evident by the neuropsychological test that brain plasticity-based training improved the flow of information in the brain [48]. In the literature, there are various training methods used to enhance cognitive skills. The main cognitive training methods that have been the subject of research are described in the following section (Figure 2.1).

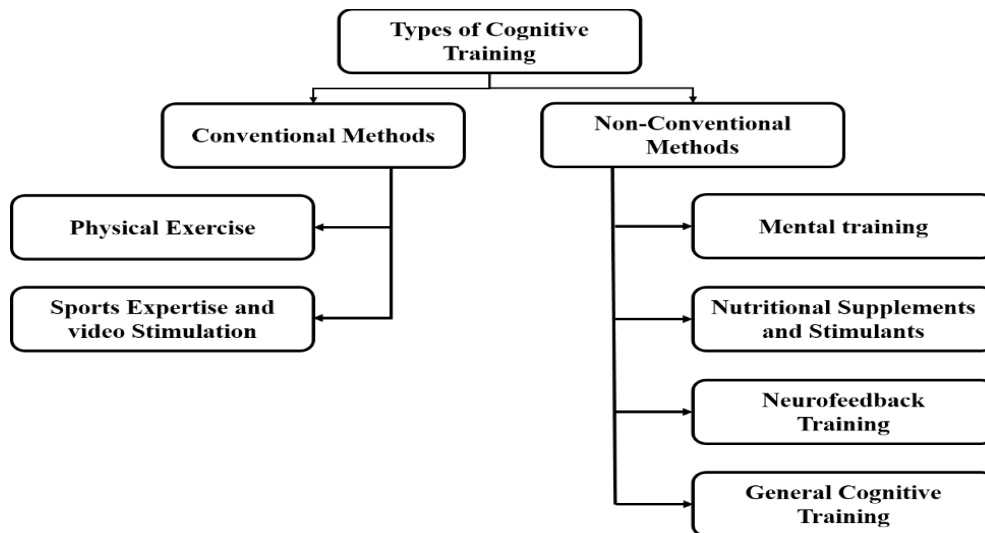


Figure 2.1 Types of cognitive training

2.1.1 Conventional Training Methods

2.1.1.1 Physical exercise

A review study in the field of cognitive training demonstrates that physical activities enhance cognitive skills [30]. Physical exercises have a long tradition of research, demonstrating broad and reliable effects on cognitive processes [49]. The results showed that physical exercise interventions often target changes in general health and reduce the risk of neurodegenerative diseases. Physical exercise is one of the necessary activities to attain elite athleticism [50,51]. It is important to note that exercise engaged the players in domain-specific practice. A review study suggested that football players can lower the incidence of injuries by participating in dynamic warm-up programs that include preventive exercises before games or during training sessions [52].

The research on physical exercises in sports had shown that experts spend more time compared to non-expert players in overall training [51]. Experts allocate more time to engaging in specific activities that are more relevant to the development of critical skills for elite performance [53]. In Baker *et al.*, the authors looked at the accumulated hours of practice within ultra-endurance triathletes [54]. The results suggested that expert athletes partake in a higher amount of quality training than less-skilled counterparts. Although the relationship between physical exercise and expert development was needed to be explored. Baker *et al.* identified the relationship between hours of practice and level of performance for karate athletes, and a similar relationship was found in team sports [53]. The results showed that experts were involved in their sports for nearly 13 years for 4000 hours before reaching the National team. Experts invested a significantly higher amount of time in one-to-one coaching, video sessions, and organized team practice. The team sports, soccer, and field hockey players were accumulated in 10237 and 9332 hours of practice for 18 years, respectively [55]. Chang *et al.* investigated that athletes of different modes of sports training correspondingly exhibited different patterns of performance in cognitive tasks [26]. Three groups of participants participated in the study; endurance, motorically complex, and control groups. No significant differences in the cognitive performance of these three groups were observed. Several studies emphasize the association between exercising and cognitive functions like working memory, attention [56–58]. The assessment of physical training observed a significant linear relationship between exercises and cognitive control. Extreme physical training would limit physiological and psychological functions.

Sports-related training improves physical abilities (*e.g.*, muscle strength, motor fitness). Excessive physical training might result in physiological maladaptation and, in turn, offset the potentially beneficial effects of exercise on cognition. Excessive or highly intense training might result in oxidative stress, which had been linked to decreased cognition or increased cognitive decline symptoms [59–61].

In sports, exercises represent a means to sustain effort toward the objectives initially set and continuously updated. The players need to involve in deliberate practice and should be adaptive to a malleable environment in different situations. This prominence is fundamental to brain plasticity and cognitive improvements because it requires a permanent cognitive demand for the activity. Also, players tend to perform in a new environment in every match and need to determine appropriate motor actions toward the desired outcome. Also, physical exercises increase the complexity which occurs due to higher demands, either self-generated or provoked by the opponents. It increases cognitive load, which means that the training level is continuously needed to be adjusted for each individual. Thus, athletes require cognitive training other than physical exercises to reduce the cognitive load for elite performance.

2.1.1.2 Sport expertise and video stimulation

The most used training method is based on the approaches of the experts and proposes the exercise related to sports practice by the athletes. The target of these exercises is to improve the visual search strategies, visual cues, recognition of patterns of game situations, and probabilities [62]. Starkes *et al.* suggest that the superior performance of the experts is not due to differences in visual abilities [63]. The difference between the expert and non-expert athlete is focused on information processing using their cognitive skills. In Helsen *et al.*, three experiments were executed to examine the relative importance of the visual system and domain-specific cognitive skills with soccer expertise [64]. The first experiment showed insignificant differences between experts and intermediate players in a target detection task. The stimuli were incorporated by slides (experiment 2) and 16 mm film (experiment 3). Thereafter, domain-specific skills like several visual fixations, fixations duration, and fixations location in solving game problems were analyzed. Results showed that the experts were significantly better than novice players. It suggested that expert domain-specific knowledge allows using of present information and making accurate decisions. Several studies supported these results and evident that expert players had better cognitive skills than novice players in domain-specific knowledge [65,66].

Occlusion paradigm-based studies showed that the experts used video-based simulation training to enhance sports-related skills [67–70]. This type of training utilized video projections of simulated field scenarios and intended to observe, understand, and anticipate the opponent's move. The video simulation was projected from the participant's perspective and presented multiple times with variable experimental conditions [71]. The results showed that video stimulation training provides the knowledge of the specific phases and situations of the game to the players.

Starkes *et al.* used video tests to assess the differences before and after cognitive training in basketball players [70]. The trained group showed that training enhances the anticipation skills compared to the control group, but insignificant benefits were observed in the field. The results emphasized the need to develop a training model that replicates and consists of game situations. Improvements in anticipation skills following video training were reported among softball players [72]. Gabbett *et al.* had significantly observed the effects of occlusion video projections based on cognitive training in the laboratory as well as field on soccer players [67]. Players were evaluated in the sport-specific skills, *i.e.*, passing, dribbling, and shooting. Sixteen players participated and were divided into two groups; experimental and control groups. The experimental group was trained to watch video clips of international matches occluded during 12 training sessions (15 minutes each) over four weeks. The training showed effective improvement in the post-assessment of the experimental group. Soccer represented complex and dynamic environments that influenced the decision-making capacity of the players. The cognitive skills, *e.g.*, working memory and attention, supported the athletes to perform effectively in such situations. Studies had shown that cognitive abilities were also specific to athletes' positions in respective sports [17]. It was identified that the physiological demand imposed on athletes during a match varied significantly depending on the player's position. It led to the development of the position-specific cognitive abilities and physical training program [73]. Williams *et al.* presented that experienced defensive soccer players had better anticipation skills than the same level defensive players regardless of the situation [17]. This was explained by the fact that the defensive players were continually engaged in anticipatory judgments during a match to read the intentions of the opponents. Whereas, anticipating the intentions of partners and opponents was less developed for offensive players. The domain-specific cognitive skills differentiated the experts from the novice and able the athletes to focus on information processing. However, few

studies show the insignificant effect of sport-specific training on the field. Thus, cognitive training had been around for several years and has shown its effectiveness in different types of sports. A cognitive training model is required which enhances the cognitive skills as well as domain-specific skills and should emphasize game situations.

2.1.2 Non-Conventional Training Methods

2.1.2.1 Mental training

Mental training activated the brain networks involved in executing the task using cognitive skills and improves performance and brain health. These training methods included mental rehearsal, imagery and visualization, and visuomotor behavior. Explanation of these methods characterized the different aspects of cognitive training to enhance the mental development of players.

a) Mental rehearsal

The training methods used to enhance the cognitive skills, primarily, mentally rehearsing the strategies intended to perform optimally in an event. Earlier evidence suggested that mental rehearsal was an effective method to enhance cognitive performance [74,75]. These studies concluded that the initial and continued ability to self-monitor, though enhanced by mental skills training, is fundamentally important for any implementation of cognitive-somatic therapy. Schema theory described that motor movements were controlled by the central structures with minimum sensory information [76]. In team sports, athletes continuously tracked the motor movements of the teammates and opponents. Memory stored this information in the form of motor patterns, which were retrieved as per the task demanded. Mentally rehearsal of specific motor patterns tended to execute the game plan, even in the absence of the requisite cues. The execution of the motor skills might be less effective without retrieving the motor patterns. A specific mental state is required to execute the motor skills optimally [77]. A level of attention is required to be modified depending upon the demands of the task. Depending upon the nature of the task (close and open skills) and efficacy of individual skill, two types of benefits observed using the mental rehearsal technique [78]. First, initiation of a skill such as attention and working memory required a specific psychological condition for optimal performance. Secondly, it is used to reinforce the execution of motor skills to increase cognitive efficiency.

b) Mental imagery and visualization

In sports, elite players widely practiced mental imagery and visualization techniques with apparently good effects on cognitive functions [79]. In this study, athletes imagined themselves performing a task (*e.g.*, dribbling in soccer), self-movement as well as movement of the opponent. The brain region (prefrontal cortex) responsible for the execution of cognitive skills appeared to be responsible for imagery processes. A review study on mental imagery demonstrated that neural representations of mental and perceptual images resemble one another as early as the primary visual cortex [80]. Decety *et al.* represented that neural operations involved in executing the cognitive skills played a role in mentally representing the actions in imagery, without generating the actual movement [81]. They applied the classical strategy “method of loci” to train the cognitive skills using a software-based developed program. Participants visualized a building, either real or imagined, and in the imagination, walked from room to room. The participant's task was to memorize the path and other substances that were instructed by the controller. In the next phase, participants retrieved the information and retraced the imagery steps and sequences. This technique enhanced the spatial navigation system of the brain while remembering the contents. This technique made use of the fact that athletes more easily recalled difficult patterns from the memory.

Maguire *et al.* compared the exceptional memorizers with normal subjects and found no systematic differences in brain anatomy [82]. The findings showed the differences in remembering the activity patterns, which reflected the use of a deliberate encoding strategy. The brain areas involved in the spatial navigation and representation were disproportionately activated in the skilled memorizers, regardless of whether the items to be memorized [83]. It was reported that participants faced the problem in remembering the items, whereas, they were using the method of loci. Thus, it attained the possibility of very high memory performance on specific patterns using such cognitive training techniques. These techniques enhanced the performance in non-contextual information, such as the sequence of numbers.

c) Visuomotor behavior rehearsal

The visuomotor behavior rehearsal (VMBR) technique was the further extension of the mental imagery and visualization. In this technique, the feedback about the performance of the physical skills provided to the participants. This technique combined the cognitive aspects of mental

imagery and physical skills and helped to enhance the cognitive skills [84]. Players followed three steps to enhance cognitive performance using this technique. In the first step, athletes relaxed themselves to be conducive to mental imagery. In the second step, the athlete participated in the training through imagery and visualization techniques. In the third step, the athlete used cognitive skills and performed under realistic conditions. After that, the performance of athletes evaluated and informed about the cognitive skills in the actual situations. This technique gave evidence of the successful outcomes in several sports, especially with closed motor skills, *e.g.*, karate, basketball, archery, tennis, and golf, gymnastics, track, and field. Karate players were examined under four conditions of cognitive training; VMBR, relaxation, imagery, and attention-placebo. Trait anxiety tests were administered at the beginning and end of the six weeks test period. The VMBR and relaxation groups exhibited lower levels of anxiety than the other groups[85]. VMBR also showed an improvement in the basketball shooting performance [86]. Another study on the archery players exhibited an improvement in shooting skill after the completion of four weeks of training[87]. The effects of self-administered VMBR training on athletic performance were observed using a sports competition anxiety test. Results indicated that the VMBR group exhibited significantly greater increases in sports performance and a decrease in sports competition[88].

The continuous repeating of this process with targeted skill, helped the participants to enhance the mental coordination between imagery and visualization technique with the actual performance. Allami *et al.* correlates visuomotor learning with event-related potentials and suggested that during mental rehearsal, neuronal changes occur in the motor networks that make physical practice after mental rehearsal more effective in configuring functional networks for skillful behavior [89]. It suggested that essential change in either the mental imagery technique or the skill might be maintained in parallel. The assessment of the cognitive skills using this technique showed the relationship of mental imagery with skill performance and associated with cognitive training. This association corresponded to the enhancement of cognitive functions and resulted in better performance because the individual maintained the skills and mental imagery techniques simultaneously. The limitation of the VMBR training is that athletes need to learn and understand the mental training techniques within the context of enhancement of cognitive skills for optimal performance. Because of unfamiliarity with the procedure, the individual

concentrated highly on the methodology and observed inattentive during the motor performance. Athletes devoted a lot of time to understand the procedure of mental training techniques.

2.1.2.2 Nutritional supplements and stimulants

Stimulants such as nicotine and caffeine helped to improve cognitive ability. In the case of nicotine, a complex interaction with attention and memory occurred [90] and demonstrated enhancement of performance on the memory task. These supplements affected different aspects of brain-like memory and attention [91] and included caffeine, nutrients, *etc.* Tieges *et al.* observed the effect of caffeine on the anterior cingulate cortex and found that consumption of a few cups of coffee strengthens central information processing [92]. Also, Smith *et al.* found that caffeine improved alertness and saccadic eye movements [93]. Soetens *et al.* experimented to investigate the temporal effects of amphetamine and memory performance were evaluated in the recall list test. The findings revealed the enhancement in long-term memory performance, and learning [94].

Diet and dietary supplements also affected the cognitive functioning of the brain. The brain demands a continuous supply of glucose to maintain the optimal processing of cognitive functions [95]. The increase in the level of glucose and release of norepinephrine stress hormones helped to enhance the working memory in demanding situations [96]. McMorris *et al.* found that creatine enhanced the energy level of the body and showed a significant effect on cognitive performance and reduced the fatigue level [97].

Stimulants enhanced memory by increasing neuronal activation or releasing neuro-modulators. It facilitated the synaptic changes and helped in storing the information. Advances in the scientific understanding of memory enabled the development of nutrients with more specific actions, such as stimulants for the cholinergic system that enhanced attention and memory. The use of nutrients and stimulants allowed the brain to learn quickly and facilitated the selective retention of the information. Several experiments using stimulants and nutrients had shown improved performance in particular tests of memory and attention. Substances that stimulate the dopamine system had demonstrated effects as the same of cholinergic drugs [98]. Muller *et al.* found that modafinil showed the enhancement in working memory of healthy subjects at harder task difficulties [99]. The results observed the increase in forwarding and backward digit span, visual pattern recognition memory, spatial planning, and reaction time/latency on different working

memory tasks. It's enhanced adaptive response inhibition and made the subjects evaluate a problem more thoroughly before responding, thereby improved performance accuracy. The combination of different substances administered at different times could facilitate users more control of their learning processes, perhaps even the ability to select specific memories of interest deliberately. In the area of cognitive enhancement using nutrients and stimulants, safety issues were likely to be most salient. For instance, a memory enhancer increases the number of trivial "junk" memories retained and suggested to use under the guidance of medical experts.

2.1.2.3 Neurofeedback Training

The neurofeedback training (NFT) approach modified human brain oscillations and was utilized to improve brain activities [100]. It was a conditioning technique employed to teach and modify the participant's neural activity by facilitating the recognition of a specific state of mind associated with particular behavior outcomes. During this training, electrodes were placed on the participant's scalp to record the EEG signals continuously and informed back about their brain activity. Frequency analysis of the EEG was commonly used to provide an estimate of the power of the sub-frequency band (*e.g.*, alpha, beta, *etc.*). The level of the power was represented graphically, auditory tones, or via some other form of illustration. The continuous practice made the participants able to correlate mental state with the neural signal.

Neurofeedback trains the individual to gain learned control over a particular frequency component of the brain activity. In sports, it was introduced by Landers *et al.* in 1991 [101]. Its efficacy was checked on the 24 skilled archery players. The neurofeedback group showed the significant effect of the training and found improvements in the shooting accuracy, whereas the control group showed insignificant improvement. In another study, 12 sessions of neurofeedback training were given to the swimming players to increase sensorimotor rhythm (SMR) and decrease high beta [102]. The results of the sports competition anxiety test indicated significant changes in brain activities with a corresponding reduction in anxiety.

Horschig *et al.* presented a review on human cognition and suggested that EEG alpha waves are generally associated with a mental state of relaxation and calmness [103]. High alpha activation was observed in the regions which were involved in the current task. The Theta band of EEG is associated with internal orientation, intuition, memory function, and cognitive load. Posterior theta also indicated low arousal, tiredness, and inattention. In contrast, at temporal sites, an

increase in theta power was observed during the encoding, maintenance, and retrieval of information. The increase in theta in the frontal region was associated with the task demands. Jeunet *et al.* experimented to evaluate the effect of the alpha wave NFT on the visual attention capability of the soccer goalkeepers and a significant correlation was found between alpha power and visual attention [104].

A preliminary study of NFT on dance performance showed effective results and teachers observed the enhancement in the dance performance of participants [105]. A study using a mixed protocol consisting of increasing alpha together heart rate variability (HRV) feedback training led the better performance in a GO/NOGO task and significantly faster reaction time [106]. In another study, the experimental group underwent twenty sessions of NFT and athletic training. Before and after the training sessions, the performance of the subjects was revealed using Kraepelin's work curve test and a significant increase in mental speed work and efficiency was observed [107]. Golf players indicated the increase in the SMR activity after the eight training sessions of NFT [108], which is results in a significant increase in shooting performance. The reduction in frontal midline theta amplitude after the NFT showed enhanced golf shooting performance [109]. The rifle shooting experts indicated the efficacy of the NFT and represented the enhancement in the performance. The results of the study found that the shooting performance is related to an increase in the SMR activity [110].

NFT was recognized to enhance cognitive functions. It provides opportunities for both enhancing intellectual and sports performance without the use of performance-enhancing drugs. The human brain is never at rest, and the EEG of the cerebral cortex showed activities in sub-frequency bands. Researchers had attempted to identify relations between cognitive activity held in the brain and frequency bands [111,112]. It was observed that NFT improves seizure disorder [113–115]. Some findings had been reported about enhancing cognitive skills. However, methodological limitations were reported, and found insignificant unambiguous changes in EEG activity [116]. This review study indicated that the selection of the appropriate protocol and location for the electrode position is very important. The trainer should be aware of feelings during training such as someone feel tired, spacey, anxious, headache, having difficulty falling asleep, or feel agitated or irritable. Participants have to wear the EEG headset during the whole NFT session. It is wearable for a limited time and after that, participants have uneasiness and showed an adverse effect of the training. It leads to alter the training protocols and quickly eliminate such

types of feelings. It was suggested that NFT should be performed under the supervision of certified professionals [117]. It was emphasized that everyone needs a different type of NFT and training sessions. Methodological flaws to document changes in EEG follows the NFT, which limits such findings. The significance of the training was focused only on specific cortex locations.

2.1.2.4 General cognitive training

The sport-context-based cognitive training approaches to athlete-focused on physical fidelity [6]. It was suggested that coaching programs should also display cognitive fidelity. Several general brain training tools and software-based computer games were developed. These computerized games tended to have no domain-specific movements and perceptual task-related information but hypothesized to exercise the brain, which was similar to exercising the body. In Gopher *et al.*, the Intelligym™ program developed by Applied Cognitive Engineering Ltd. was created to enhance cognitive skills [118]. It was a computer-based video game, and a player must choose to control the movement of a space spaceship while firing missiles to destroy a fortress. The players protected the ship from the opponent's missiles and managed the resources. This training required visuospatial orientation to manage information processing and high attentional resources under time constraints. It was demonstrated that the 10-hour training significantly improved cognitive functions. A pre-workout evaluation or a placebo group to compare the results was required. Lee *et al.* showed space fortress put more cognitive load and observed a decrease in brainarea related to attention, *i.e.*, dorsolateral frontal cortex [119]. Wentink *et al.* used the Lumosity to enhance cognitive functions like attention and working memory [120]. The results demonstrated the effect of the training on the performance of cognitive tests that were similar to the computer-based training in the training group. In the literature, there are several general cognitive training methods used to improve cognitive ability. The main cognitive training methods that have been the subject of research are described.

a) Stroboscopic training

Stroboscopic glasses, called vapor strobe, were used to enhance cognitive functions. Wearing strobe glasses produces intermittent vision that interrupts the flow of the visual information and reduces the information available in the field to guide the movements [121]. Catching a ball under conditions of strobe vision forces extrapolated the scenes to judge the trajectory of the ball

correctly. Individuals must make better use of the visual information available to them and might thus become more sensitive to other sources of sensory information. Some scientists showed that this process could lead to the perceptual and attentional abilities of athletes, particularly those with visual-motor control [121,122]. Mitroff *et al.* evaluated transfer effects on the field for professional ice hockey players. The results showed that wearing strobe glasses during 16 hockey practices (10 min per practice) allowed players to improve their performance by 18% compared to players training without glasses. The use of stroboscopic glasses over transparent glasses helped to retain information in short-term visual memory during a memory task [121]. The results indicated that this training has the potential to improve the aspect of visual memory of athletes. Perceptual-cognitive measures evaluated before and after training was spatial attention, sustained attention, and visual sensitivity [123]. Stroboscopic eyewear had revealed improvements in sensitivity to central vision movement and transient attentional skills. Smith *et al.* had shown that stroboscopic training improves anticipatory time, *i.e.*, the ability to predict a stimulus in motion at a specific time [124]. It was suggested that the comparison of the experimental group with a control group is very important. Whereas, Wilkins *et al.* had tested the effects of wearing stroboscopic glasses during training and found insignificant benefits of training on sports performance [125]. In another study, the effect of stroboscopic vision training was given to fifty-one female volleyball players. The results showed the improvement in the non-sport-specific context, but less effective for improving sport-specific skills [126]. The limitation of this training is that participants have to wear stroboscope glasses throughout the training sessions.

b) Quiet eye training

Vickers [127] used quiet eye training and showed performance improvement in novice learners. It was identified that quiet eye training improves performance against the increasing anxiety in pressure conditions. This study was conducted on 30 novice participants, and results showed that the training group performed more accurately in golf putting as compared to the control group, although both groups experienced greater cognitive anxiety. Both groups displayed an increase in quiet eye duration and a decrease in performance error. Another study on quiet eye training indicated that the control group was able to control under pressure conditions in the retention period while the training group was better than the control group in post-measurement [128]. The mobile eye tracker was used to measure gaze and eye fixation. The quiet eye training

intervention was also tested at visuomotor control and putting performance of elite golfers under pressure, and in real competition [129]. Twenty-two elite golfers participated in the study, and training consists of video feedback of their gaze behavior. The training group maintained their optimal quiet eye duration under pressure conditions and performed better significantly than the control group with subsequent effects on performance. The training showed its efficacy in transfer to the golf course. Causer *et al.* demonstrated the effect of training on the shotgun shooting performance of the players [130]. The results indicated that the training group significantly improved the shooting accuracy from pre-test to post-test. It was suggested that the evaluation of pre-test to post-test differences is also important. The quiet eye training intervention helped to maintain visual attentional control [131]. The training group performed significantly better in the pressure test compared to the control group. The quiet eye training also has a similar limitation as stroboscopic training that participants need to wear an eye gaze camera for this training. Wearing this device for long training sessions makes the players uncomfortable.

c) Multiple object tracking training

Multiple Object Tracking (MOT) was used to study and train the cognitive skills of the athletes. It was used as a high-standard cognitive task in a variety of populations because it is safe from the risk of toxicity with minimal time investment [132]. Each trial of MOT consists of three phases. In the first phase, the indexation phase, several identical objects are presented on the screen. Few objects are highlighted as targets and remaining objects as distractors. In the second phase, the tracking phase, all target objects change the color as the same of distractors and start to move on the screen in random motion. Participants are asked to track the objects continuously. In the third phase, the identification phase, circles stop to move, and the participant task is to select all target objects. The number of targets and distractors was always kept fixed, *i.e.*, four targets and four distractors. Faubert *et al.* proposed that the cognitive training model should have motor control demands and assist the athletes in improving mental abilities [13]. MOT was used to train the athletes and significant changes in their cognitive capacity were observed. Meyerhoff *et al.* presented a tutorial review on MOT paradigm and revealed that it is a high-level cognitive task to stimulate a large number of neural networks and work simultaneously during the exercise [132,133]. It solicited the networks involved in the integration of complex movement, distributed, sustained, and dynamic attention as well as working memory. It was observed that

MOT improves cognitive skills like attention, working memory, and neurological evidence that approved its efficacy. Parsons *et al.* gave evidence of cognitive enhancement of participants through MOT training using neuropsychological tests and correlates with electroencephalography [34]. In this study, twenty young adults were involved, *i.e.*, 10 participants each for the training group and control group. The results revealed that the training group improved attention and working memory compared to the control group. Training led to changes in the activity of the corresponding brain function at frequencies involved in attention (Theta/Beta). The authors suggested that the transfer of the benefits of 3D-MOT should be observed in daily life activities.

MOT training improves the cognitive skills of the athletes. Romeas *et al.* assessed the transfer capability of the MOT training in elite soccer players [31]. The experiment was conducted on twenty-three soccer players and was divided into three groups; MOT group (MOT training), active control group (watched world cup soccer videos), and passive control group (no training). Results revealed that the MOT group significantly improved the passing ability between pre and post-session (15%). Participants in the experimental group reported improvements in confidence levels in decision-making. Results indicated the potential skill transfer from MOT sessions to on-field performance. MOT training also benefited older adults to improve their cognitive skills. Legault *et al.* demonstrated the effect of the MOT training on the younger and older adults[4]. The results described that the young people had more cognitive capacity, whereas older adults showed an improvement in the tracking skills after five weeks of cognitive training.

MOT enhances the cognitive function in healthy young adults, *i.e.*, attention and working memory [34], transfer to biological motion perception within laboratory settings in aging populations [4], and soccer field [31]. These MOT training studies were employed based on the speed threshold, which was adjusted by the staircase procedure. In the staircase procedure, if the participant selected the target circles, then the speed of the circles increased in the next trial. The unsuccessful attempt of the circles led to a decrease in the speed.

In dynamic team sports, such as basketball, hockey, and soccer, knowing “when-and-where” to look was the difference between a successful and unsuccessful game [71]. The ability to “read” the game (*i.e.*, perceptual-cognitive skill) distinguished expert and non-expert athletes [64,71]. Athletes in team and individual sports required high-level cognitive skills with superior vision

[5,13]. It was identified that the functioning of the cognitive skills of players alters by a few other factors like the number of targets and distractors, background noise, and field of view. Firstly, players must be able to track the position of the other players (teammates as well as opponents) in the field. The number of players nearby him continuously varied depends upon the situation. Secondly, critical visual information spreads throughout the visual field. The field was divided into multiple chunks, and information was distributed non-uniformly in each chunk. Players needed to recognize the area of the focus and applied the cognitive resources at the identified area to grab useful information. During tracking the ball, the information confronts the athlete anywhere in the field. Players must concentrate on the localized region as well as dynamics of the surroundings, increased attention load [62,64,65,71]. Thirdly, the presence of background noise (*e.g.*, audience noise) hinders the effective functioning of cognitive skills, [46,134]. The cognitive performance in the attentional-based tasks disturbed by the level of noise, even within the moderate ranges [135]. It was evident that attention and working memory capacity decline as a consequence of the background noise. Changes in the EEG brain waves were observed in the presence of the background noise. Brain waves related to attention, *i.e.*, the amplitude of the beta and theta, significantly decreased by the exposure of the background noise [28]. Therefore, assessment of cognitive skills with the influence of these factors needs a part of the cognitive training.

2.2 Measures of Cognitive Skills

The most important aspect of applying cognitive training is to determine its efficacy. These training programs are used to enhance the cognitive skills and techniques are used to evaluate the cognitive abilities of the human brain. Scharfen *et al.* presented a review on the measurement of cognitive skills in experts and elite athletes [136]. The observation of the study suggested the use of neuro-cognitive tests to quantify differences among experts and non-experts as well as elite athletes and non-elite athletes. The cognitive skills had been evaluated in two ways, *i.e.*, psychological and physiological assessment. In psychological assessment, the participants are asked to complete the tasks that require cognitive skills. Several studies have used psychological tests to evaluate cognitive skills. Owen *et al.* studied the effect of the regular use of the cognitive tests and found enhancement in the cognitive functions [137].

Verburghet *al.* investigated the working memory capacity of the soccer players using Digit span (Dspan) [138]. Participants were divided into three groups, elite, non-elite, and no-athletes. Elite soccer players showed significant differences in working memory tests compared to other groups. The results suggest that cognitive skills are effectively measured using psychological tests. Furleyet *al.* used the Corsi Block Tapping (CBT) test to evaluate the working memory of the basketball players [139]. Various studies had shown the significant use of Dspan and CBT to measure the working memory capacity [140–143]. N-back test was used in previous studies to investigate the working memory capacity [144,145]. Brouwer *et al.* significantly found the relation between the working memory task and EEG frequency bands [145].

Attention was also measured using psychological tests. Heppet *al.* performed the d2 test to measure the attentional capacity of the elite and recreation soccer athletes [146]. Results showed that elite athletes were significantly better than recreational athletes. The efficacy of the d2 test to measure attention was supported by various studies [147,148]. Various studies had measured the attentional capacity using stroop tests, continuous performance tests, and identification (IDN) tests[135,149–152]. The results of these studies suggest that the psychological test significantly measured cognitive skills.

Cognitive processes held in the brain and EEG recording had been recognized as the important measure of brain activities. Various studies had emphasized understanding the functional connectivity as well as changes in brain waves associated with cognitive skills [153–155]. Parsons *et al.* examined that MOT training significantly improved the cognitive functions with correlation with brain waves [34]. Results demonstrated a significant increase in beta and a decrease in theta frequency power of the frontal region in post-measurement and found an enhancement in attention and working memory. It was supported by the psychological tests, *i.e.*, d2 and memory span tests. It indicates that attention and working memory share the same temporal region and activated through cognitive training.

Several studies say that the significant synchronization in beta and alpha with enhancement in working memory and attention [155–159]. Mazheret *al.* assessed the cognitive load in the repeating cognitive task [153]. A significant increase in alpha coupling strength was observed and found a decrease in cognitive workload. Puma *et al.* identified the significant desynchronization in theta and synchronization in alpha frequency at the frontal region in

correlation with cognitive workload [36]. The results of these studies significantly correlated the EEG frequency bands with cognitive skills. It suggested that EEG frequency bands at the frontal region of cortex influenced the attention and working memory.

In this chapter, a brief review of the literature on cognitive enhancement methods was described. To understand the impact on cognitive skills and sports performance, screening of prominent studies was done. The factors which affect cognitive skills and decrease cognitive functions were assessed. Also, the significant contribution of EEG frequency bands and psychological tests with cognitive skills were described.

CHAPTER 3

Methodology

3.1 Cognitive Training Model

The literature described the several characteristics of the cognitive training model, which are following: free from toxicity and does not have any side effect; no fatigue; require a minimum time to enhance the skills; should not need the help of experts during the training; work without any external wearing device or hardware; and helpful in decreasing the cognitive load. Besides these factors, it should enhance domain-specific skills. Moreover, it incorporates the factors, which cause a decrease in cognitive skills. So that, the cognitive training paradigm increases player's performance in the dynamic field under the influence of these factors. Three important factors are identified in the literature; several nearby players, interfering noise, and field of view. The MOT task fulfills these requirements. Earlier studies of the MOT training works on the speed threshold procedure and designed with four targets and four distractors. In this study, MOT task is designed which incorporates the aforementioned factors.

MOT task was designed using UNITY game engine (UNITY 4.3 by Unity Technologies).The training model contained 15 levels (level 0 to 14), and different complexities were introduced at each level. Before the start of each level, a window (Figure 3.1) appeared on the screen, and by clicking on the "Play" switch, the task started. The fifteen levels included sound distractors, hurdles, multiple division of screen, variation in the number of targets, distractors, and speed.



Figure 3.1 Starting window of the task

Each level of MOT is performed in three phases. The first phase is the indexation phase, as represented in Figure 3.2(a). In this phase, some static circles, *i.e.*, targets (green color) and distractors (blue color) displayed for 5 seconds in random positions on the computer screen. In the second phase, the tracking phase, all circles turned blue and started moving randomly on the screen. The arrows represent the motion of circles, as depicted in Figure 3.2(b). Circles moved for 10 seconds, and the participant's work was to track the target circles. Circles bounced at the border of the walls and also when colliding with another circle. In the third phase, the identification phase, as shown in Figure 3.2(c), circles stopped to move, and participants were directed to select the target circles with the aid of the computer mouse. At the successful attempt of the level, participants moved to the next level (Figure 3.3), and an unsuccessful attempt led to repeat the level (Figure 3.4). Table 3.1 summarized the details of each level of the MOT model.

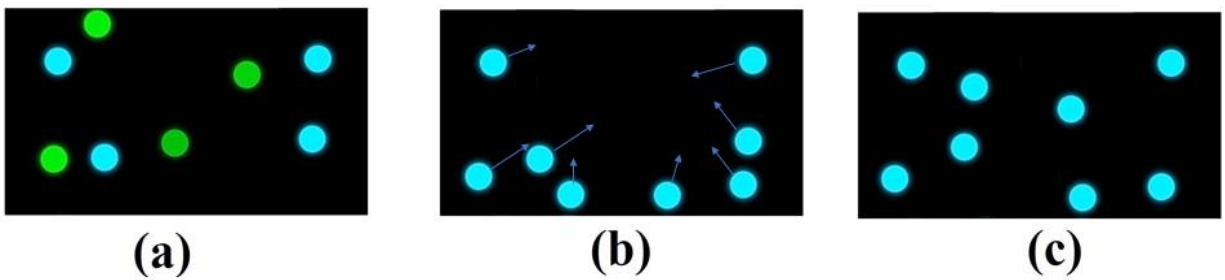


Fig. 3.2 Three phases of MOT (a) Indexation phase, (b) Tracking phase (c) Identification phase

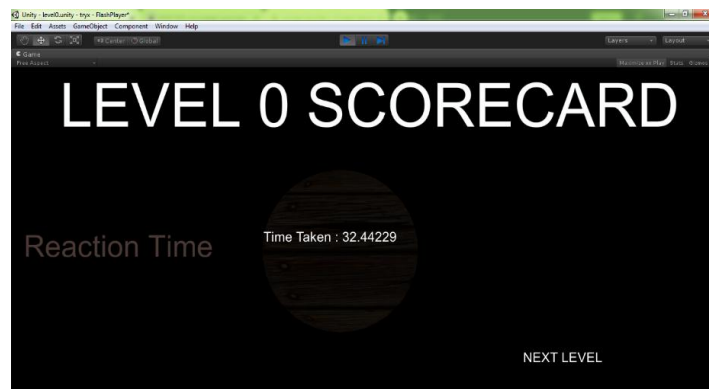


Figure 3.3 Window appeared at successful attempt of task

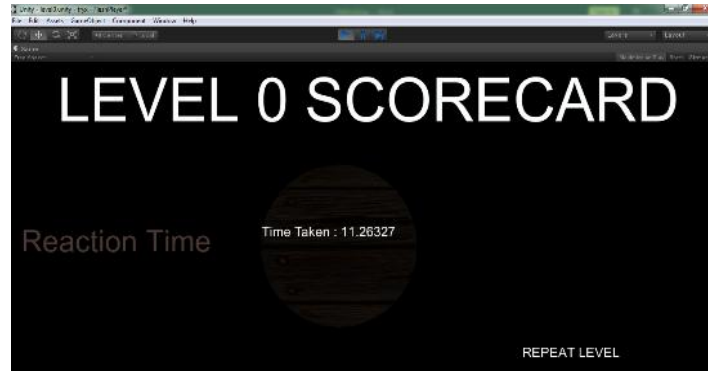


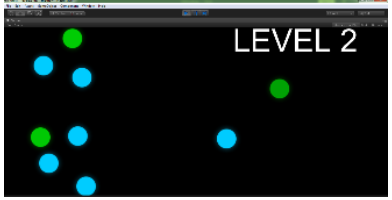

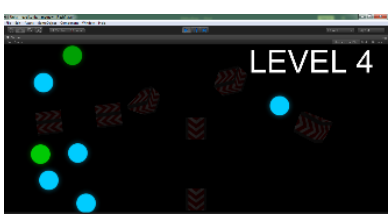
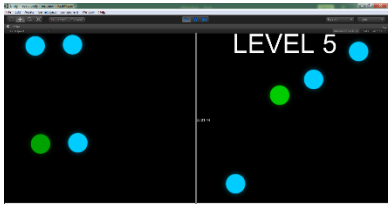
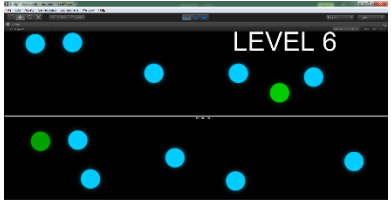
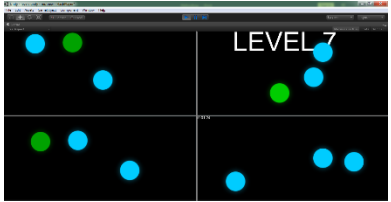
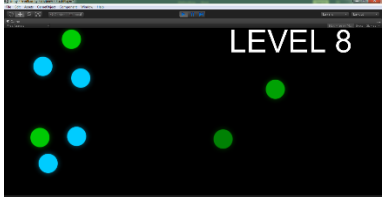
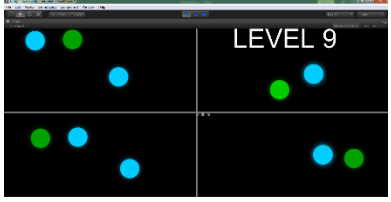
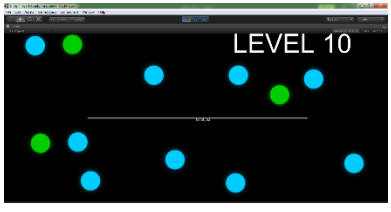

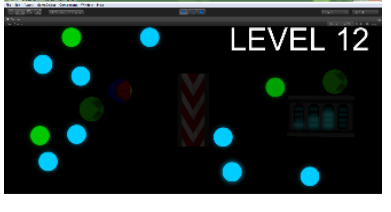
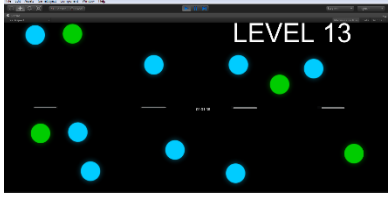
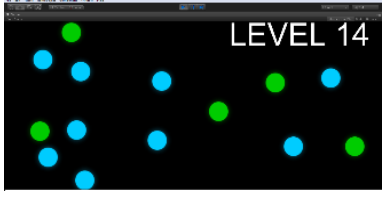


Figure 3.4 Window appeared at successful attempt of task

Table 3.1 Summarized detail of each MOT level

Number of levels	Factors included	Number of targets	Number of distractors	Screenshots of the levels of MOT module
Level 0	No	02	05	
Level 1	04 fixed hurdles added	02	05	
Level 2	No	03	06	
Level 3	01 high speed circle and sound distractor	02	06 (05 with normal speed and 01 with high speed and sound distractor)	

Level 4	01 high speed circle and sound distractor	02	07 (05 with normal speed; 02 with high speed and sound distractor; initially disappear)	
Level 5	Screen was divided vertically in two parts	02 (01 target in each part)	06 (03 in each part)	
Level 6	Screen was divided horizontally in two parts; sound distractor	02 (01 target in each part)	10 (05 in each part; 01 fixed, 03 moving at normal speed, 01 moving at high speed)	
Level 7	Screen was divided into four parts	03 (01 target in each part)	09 (07 moving at normal speed, 02 are moving at high speed)	
Level 8	No	04	04 (01 fixed, 03 moving)	
Level 9	Screen was divided horizontally in two parts; sound distractor	04 (01 target in each part)	08 (02 in each part)	

Level 10	Screen was divided semi horizontally in two parts; sound distractor, moving hurdles	03	09 (05 moving at normal speed, 02 fixed, 02 at high speed)	
Level 11	Sound distractor	04	04 (01 fixed, 03 moving at normal speed)	
Level 12	Sound distractor, 04 hurdles	03	09 (01 fixed, 08 moving at normal speed)	
Level 13	Screen had four dividers horizontally, 02 different sound distractors	04	08 (02 fixed, 02 at high speed, 04 at normal speed)	
Level 14	No	05	09	

3.2 Optimal Determination of Wavelet

The aim of recording the EEG signal was to extract meaningful information to study the influence of cognitive training. These signals have low amplitude and are easily contaminated by the artifacts. These artifacts overlap with EEG frequency bands with a larger magnitude and change the information related to cerebral activities. These signals are affected by several types of artifacts, such as eye blink, muscle artifacts, baseline artifacts, *etc.* The combination of

independent component analysis (ICA) and wavelet transform(WT) is used as a suitable method to denoise the EEG signals [160]. The wavelet transform-based technique presented an efficient way to extract the sub-frequency bands of EEG [161]. Hundreds of wavelets are available, and information obtained varies with different types of wavelets. Several types of wavelets are used to denoise the EEG signal, such as Daubechies, Coiflets, Biorthogonal, *etc.* [162]. The selection of wavelets is essential because the characteristics of the wavelet function should be synchronized with the signal. Here, a comparative study to evaluate the optimal wavelet based on 109 wavelets of seven families has been carried out.

3.2.1 Participants

Twenty-five football players (age 18-23 years, mean age 20.63 ± 1.69 years) were selected, and their EEG signals were recorded while playing the MOT. All the participants had no history of neurological disease. Participants were informed about the MOT task and EEG data recording procedure before starting the experiment. A questionnaire on computer game habits was filled up by the participants. The participants engaged in computer games for more than 20 hours in a month, were not enrolled. Signed informed consent was taken from each participant. The research protocol was approved by the University Research Ethics Committee.

3.2.2 Task and Stimuli

The MOT was presented on a 17" LCD monitor with a resolution of 1366×768 pixels. The full display subtended at a viewing distance of 75 cm. Participants were seated (inside a dark room) on a comfortable chair in a convenient position. It was ensured that viewing distance and participant's position remains constant throughout the experiment. A session was given to the participants in which they were made familiar with MOT and experimental procedures. EEG data were recorded while playing the MOT (section 3.1).

3.2.3 EEG Data Acquisition

The particular device had been widely utilized by the research community and depicted satisfactory performance. Previous research employed the Emotiv Epoc for collecting the EEG data to investigate the efficacy of the cognitive training [163]. Je-Hun Yu *et al.* classified the color imagination data of EEG and ERP which is recorded using Emotiv Epoc [164]. Another study presents a review of the portable EEG technologies and suggested that Emotiv Epoc is

good for academic research [165]. However, we have maintained good connectivity of the electrodes with the scalp. The color map of the emotive was observed throughout the recording session and was maintained green color of each electrode. The green color indicates the good quality of the signal.

EmotivEpoc (Emotiv incorporation, model Epoc+, San Francisco, U.S.A.) was used to collect the EEG data (Figure 3.5). It is a 14 channels system used to sample the data at a 128 Hz sampling frequency. Data were collected as per the international 10-20 system at AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, and AF4 electrodes locations (Table 3.2).



Figure 3.5 EmotivEpoc+

Table 3.2 Description of 14 electrodes

S. No.	Channel Name	Channel Location
Ch1	AF3	Anterior frontal left hemisphere
Ch2	F7	Frontal left hemisphere
Ch3	F3	Frontal left hemisphere
Ch4	FC5	Frontal central left hemisphere
Ch5	T7/T3	Temporal left hemisphere
Ch6	P7/T5	Parietal left hemisphere
Ch7	O1	Occipital left hemisphere
Ch8	O2	Occipital left hemisphere
Ch9	P8/T6	Parietal left hemisphere
Ch10	T8/T4	Temporal left hemisphere
Ch11	FC6	Frontal central left hemisphere
Ch12	F4	Frontal left hemisphere
Ch13	F8	Frontal left hemisphere
Ch14	AF4	Anterior frontal left hemisphere

The impedance between the scalp and electrodes was maintained below $5\text{ K}\Omega$, and conducting gel was used, which makes good conductivity. Figure 3.6 shows the green color for good connectivity between electrodes and scalp. Figure 3.7 shows the experimental setup with the subject while taking the EEG signal from the scalp. EEG signals were acquired in the computer system by Emotiv test bench v1.5.0.3 (Figure 3.8).

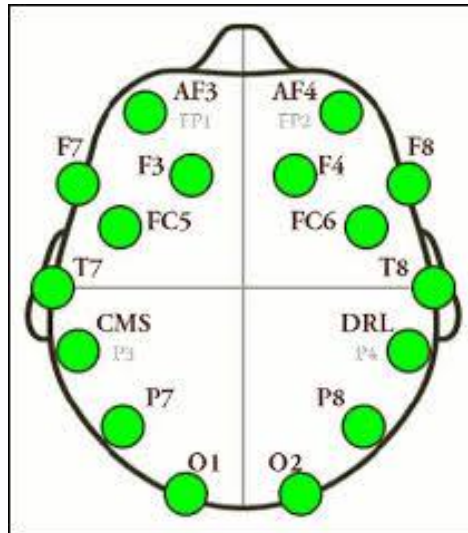


Figure 3.6 10-20 EEG electrodes system of EmotivEpoC+



Figure 3.7 Experimental set up with subject while taking EEG signal

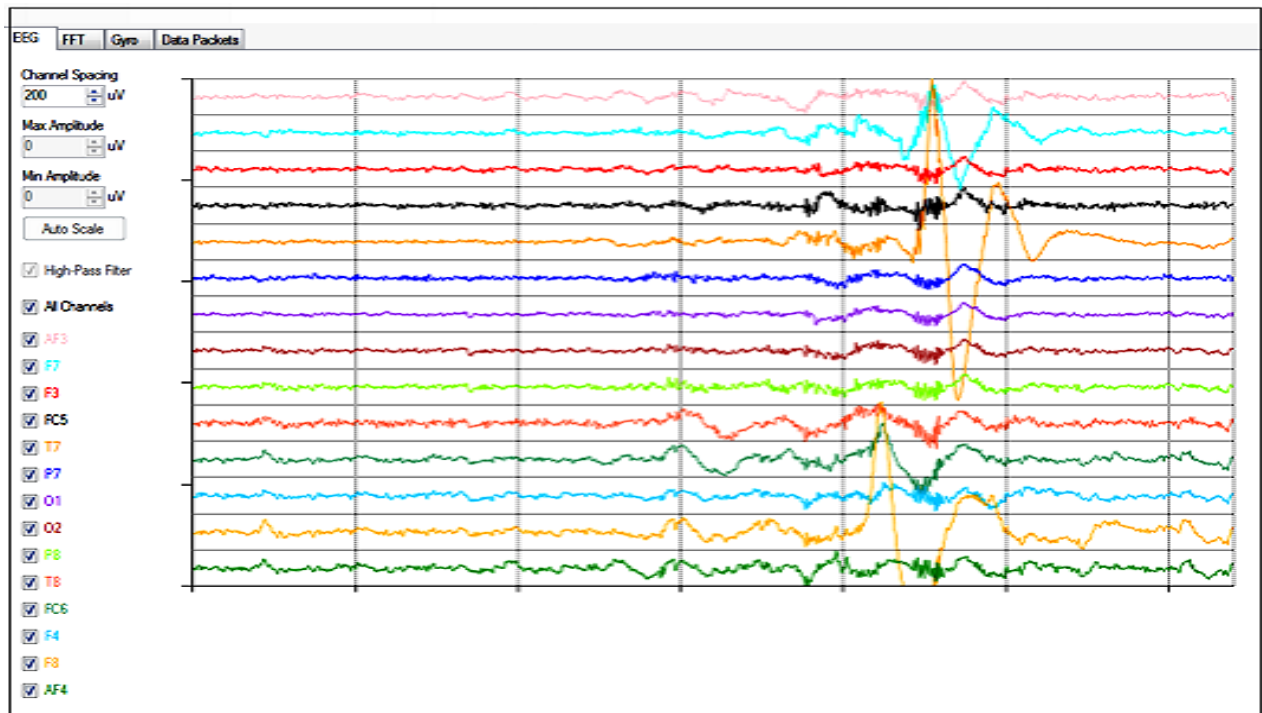


Figure 3.8 EEG data acquisition during experimentation using 14 channels

3.2.4 EEG pre-processing and Selection of Optimal Wavelet

The analysis of the EEG signals was divided into two parts, pre-processing through a combination of ICA-WT and selection of optimal wavelet. ICA performed fast convergence and directly found the independent components of any non-Gaussian distribution. ICA is proven useful to isolate target artifacts into separated independent components [166]. The wavelet-based multiresolution analysis is shown to be more effective while better preserving the structure of the EEG signal in both the time and frequency domain [162]. In recent years, the combinations of ICA and WT are well accepted for artifact removal and have shown promising results in practical applications [160,167,168]. The complete procedure of artifact rejection and wavelet selection was divided into three parts (described in Figure 3.9).

Part 1 (EEG pre-processing)

In the first step, EEG signals were pre-processed to remove the artifacts from the raw signal. The following steps were followed to remove the artifacts:

- 1) EEGLAB (an MATLAB plugin) is used to process the raw data (named as R), in which a bandpass filter with 0.5 Hz to 63 Hz cut-off frequencies was applied to the raw signal [169].

- 2) ICA infomax algorithm was applied to separate the source signals from the artifacts and obtain 14 independent components. The topographical images of the components were visually evaluated and identified the artifact components. The power spectrum of each component was evaluated and identified the component having power line noise (50 Hz). The components having the artifacts were removed and obtain the clean signal.
- 3) The artifact components were removed based on the two conditions. First, the frequency range of the few artifacts are overlapped with the desired EEG frequency [170] and removal of artifact components might result in information loss. As the data contain only 14 components, maximum of two components were removed. Second, the correlation coefficient (r) was calculated between the raw signal and clean signal for data of each channel and should be high ($r > 0.9$) [166]. It showed that the rest of the signal did not change significantly.
- 4) EEG signal consists of sub-frequency bands; delta (0.5-4Hz), theta (4-8Hz), alpha (8-12Hz), beta (12-30Hz), and gamma (30-45Hz) and include all valuable information. Wavelet transform is the optimal technique to decompose the EEG signal into its sub-frequency bands [171]. It is useful to remove the noise from the signal. This is a combination of low pass filter and high pass filter, low pass filter's coefficients are named as approximation coefficients (cA) and high pass filter's coefficients as detail coefficients (cD). Each consecutive decomposition divides approximation coefficients into detail and approximation coefficients. This process is performed until the desired frequency response is attained and this process is called decomposition tree. In this study, wavelet transform is applied and decomposed signal up to 7th level using selected wavelet (Figure 3.10). The approximation coefficients of the 7th level (cA7) have a frequency range 0-0.5 Hz (baseline noise) and make these coefficients zero.
- 5) After that, wavelet thresholding is applied. It is of two types, i.e., hard and soft thresholding. Hard thresholding is more sensitive to small changes in the signal and is unstable as it tends to have a bigger variance. However, soft thresholding tends to bigger bias due to the shrinkage of large wavelet coefficients [172]. The soft thresholding is more stable than the hard thresholding and given by

$$f(x) = \begin{cases} x - Tx > T \\ 0 & x \leq T \\ x + Tx < -T \end{cases} \quad 3.1$$

6) Reconstruct the signal and name as D1.

Part 2 (EEG signal quality analysis)

Three methods were used to evaluate the quality of the cleaned EEG signal, which was obtained after the procedure of pre-processing.

- 7) Firstly, the statistical difference between raw (R) and clean (D1) signals was assessed. If the significant difference between the two signals was not observed, then the data of that participant were rejected. Four features were calculated for R and D1; skewness, energy, root mean square, and power spectral density and statistical differences for each feature were determined using a t-test.
- 8) Secondly, the efficacy of the artifact removal process was evaluated by adding and removing the artificial noise. The artificial noise (random noise and white Gaussian noise at SNR = 20 dB) were added to the clean signal (D1 which was obtained after step 6). Then, the noisy signal was cleaned by the process (follow steps 1 to 6) and obtained a clean signal which is named D2. Correlation coefficient and energy retain figured out between D1 and D2.
- 9) The sub-frequency bands of the EEG are used to examine the cognitive functions. In the next step, five frequency components of the EEG (delta, theta, alpha, beta, and gamma) were assessed using wavelet transform for raw and clean (D1) signal. Four features (as in step 7) were calculated for all components of EEG (R/D1) and feed to support vector machine classifier with five-fold cross-validation. The SVMs are used in the context of pattern classification to discriminate between two classes. Linearly inseparable data sets are mapped to a higher dimensional space using a kernel function such that they become linearly separable. An optimization problem is then solved to find the hyperplane that maximizes the margin between the two classes. Fraser et al. used the support vector machine (SVM) classifier to identify the bio-signal quality [173]. SVM effectively distinguished the contaminated and clean signal. At high classification accuracy, SVM classify the clean and contaminated signal, whereas, at low classification accuracy, it classify the majority of the EEG signals as contaminant-free.

Part 3 (wavelet selection)

10) The selection of a wavelet function is an important step and part of wavelet analysis to demonstrate the advantages of WT in denoising, component separation, coefficient reconstruction, and feature extraction from the signal in time and frequency domains. The optimal wavelet function was selected based on the compatibility with the EEG signal characteristics to be analyzed. The selection of optimal wavelets helped retain the original cortical signal and enhanced the frequency spectrum of the denoised signal. Each wavelet function has its shape and wavelet families, including daubechies, symlets, coiflets, haar, meyer biorthogonal and reverses biorthogonal were considered in this study. A total of 109 types of wavelets (described in Table 3.3) were used to evaluate their compatibility with the recorded EEG signals. Steps 1 to 9 were repeated for each type of wavelet. The similarities of these wavelet functions with recorded EEG were analyzed using correlation, energy ratio between two clean signals (D1, obtained in step 6 and D2, obtained in step 8) as well as classification accuracy of SVM classifier (obtained in step 9).

Table 3.3 Types of the wavelet

Wavelet number	Wavelet family	Wavelets	No. of wavelets
1-15	Biorthogonal	bior1.1, bior1.3, bior1.5, bior2.2, bior2.4, bior2.6, bior2.8, bior3.1, bior3.3, bior3.5, bior3.7, bior3.9, bior4.4, bior5.5, bior6.8	15
16-20	Coiflets	Coif1 to coif5	5
21-65	Daubechies	db1 to db45	45
66	DMeyer	dmey	1
67	Haar	haar	1
68-82	Reverse Biorthogonal	rbio1.1, rbio1.3, rbio1.5, rbio2.2, rbio2.4, rbio2.6, rbio2.8, rbio3.1, rbio3.3, rbio3.5, rbio3.7, rbio3.9, rbio4.4, rbio5.5, rbio6.8	15
83-109	Symlets	Sym2 to sym28	27
Total			109

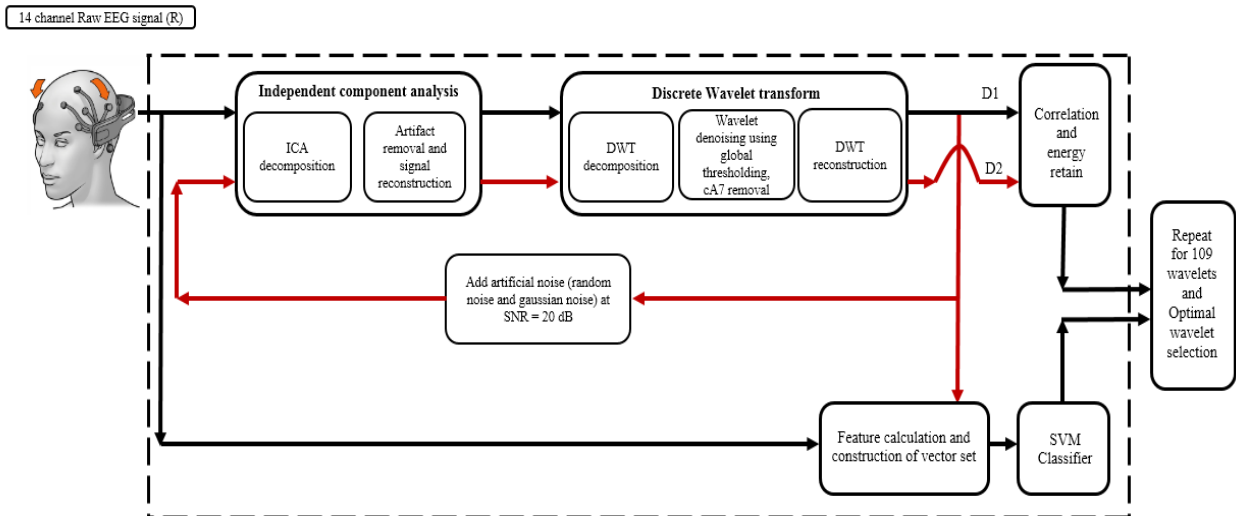


Figure 3.9 Block diagram represents flow of work

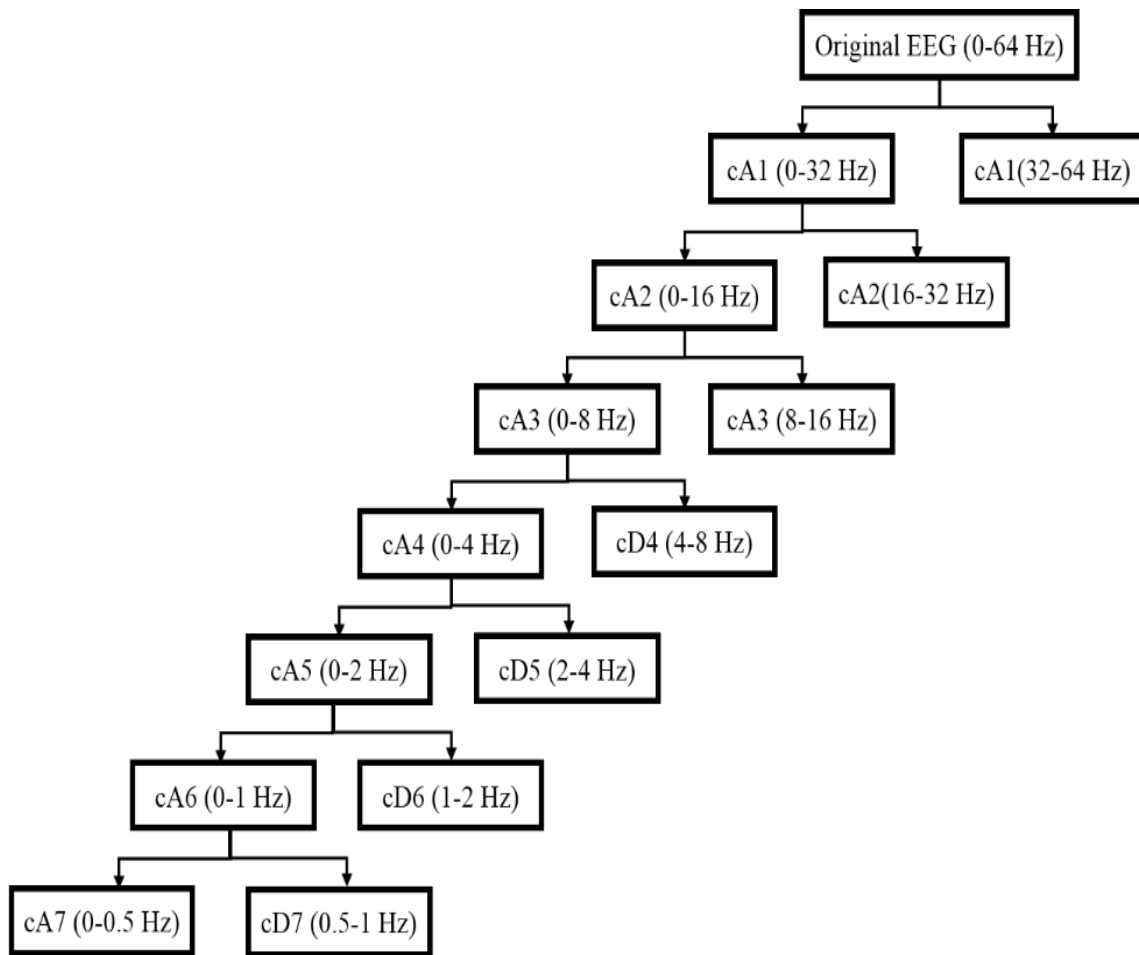


Figure 3.10 Wavelet decomposition

The description of mathematical tools used in this section is given here.

a) ICA

The procedure of ICA is the widely accepted tool for decomposing the multivariate EEG data into its independent, non-gaussian components [174]. Infomax ICA algorithm was applied to separate the source signals from the artifacts using the EEGLAB toolbox in MATLAB. Figure 3.11 shows the scalp topography for 14 channels after the application of ICA. Figure 3.12 presents the enlarged view of a single component of ICA. Figure 3.13 shows the plot of the power spectrum of a single ICA component. The ICA models were applied for EEG analysis with underlying plausible assumptions:

- a) The cerebral and artifactual sources are linearly mixed and are statistically independent
- b) The number of observed signals, S, are equal to the number of ICs
- c) Propagation delay through the mixing medium (*i.e.*, brain, scalp, *etc.*) is negligible

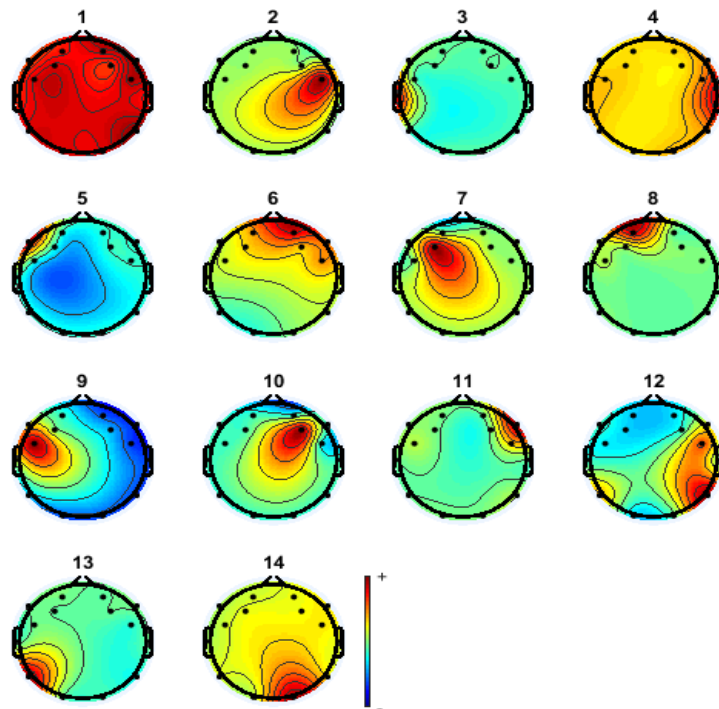


Figure 3.11 Independent components for the 14 channels through ICA

ICA model of n linear mixtures, x_1, x_2, \dots, x_n of independent components s_1, s_2, \dots, s_n is given by

$$x_j = a_{j1}s_1 + a_{j2}s_2 + a_{j3}s_3 \dots \dots \dots + a_{jn}s_n, \text{ for all } j \quad (3.2)$$

The matrix notation of the ICA model of Equation 3.2 for the observed EEG sources S is expressed mathematically as

$$X = A * S \tag{3.3}$$

where, X is the linear mixture of sources, A is the unknown mixing matrix. Infomax ICA algorithm to calculate the unmixing matrix (W) so that the components (u) are as independent as possible and get the best approximation of S as

$$u = W * X \approx S; \quad \text{where, } W = A^{-1} \tag{3.4}$$

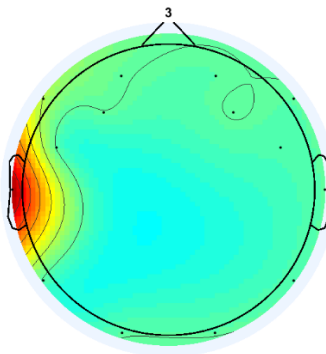


Figure 3.12 Single channel ICA component

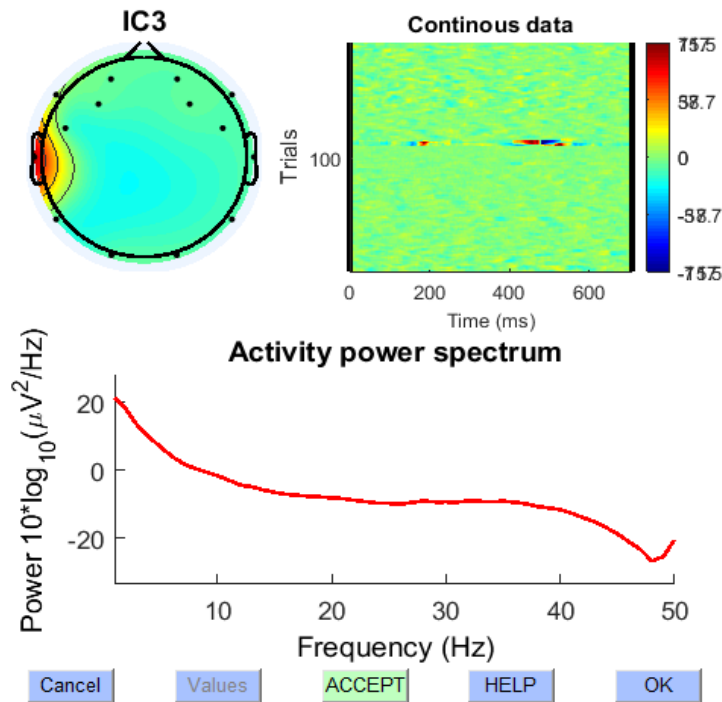


Figure 3.13 Plot of power spectrum of independent component

b) *Wavelet transform*

The Wavelet Transform (WT) is a stable and suitable method for signal transformation in biomedical signal processing [170]. It decomposes the signal into time and frequency simultaneously. It's a better technique to decompose the signal in low-frequency components. It works as a bandpass filter and segregates the signal into two frequency bands. The weights associated with low frequencies are called approximation coefficients (cA), and weights associated with high frequencies are called detailed coefficients (cD). Figure 3.10 shows the 7th level decomposition of the original signal using WT. These features make WT suitable for denoising of EEG signals. The wavelet denoising is based on the Mallet Signal Decomposition Algorithm. It removes the high and low-frequency approximation of the relevant part of the signal and reconstructs it to form the EEG signal. The wavelet denoising performed in three steps:

- a) Signal decomposition with selected mother wavelet and level of decomposition
- b) Threshold of the resulting wavelet coefficients
- c) Inverse wavelet transforms for the reconstruction of denoised signal

The WT means choosing subsets of the scaling factor 'a' and shifting factor 'b' of the mother wavelet which is given by:

$$\psi_{a,b}(t) = \frac{1}{\sqrt{a}} \psi\left(\frac{t-b}{a}\right) \quad (3.5)$$

c) *Support vector machine*

Support Vector Machine (SVM) is a widely used classifier utilizing the method of supervised machine learning [175]. The SVM classifier aims to construct an optimal hyperplane that separates two or more datasets for classification in the test data. The optimal hyperplane is constructed to obtain the maximal margin from the nearest sample known as the support vector. In the case where the datasets are not linearly separable in the finite-dimensional space, the data can be remapped into a sufficiently higher-dimensional space. This mapping is conducted by using a defined kernel function, which presumably ensures an easier separation of the datasets. The hyperplane defined in the higher dimensional space can be viewed as a non-linear separating hyperplane in the original finite-dimensional space.

$$Accuracy = \frac{TP+TN}{TP+TN+FP+FN} \times 100\% \quad (3.6)$$

where, TP, TN, FP, and FN are the number of true positives, true negatives, false negatives, and false-negative events, respectively.

d) *Features*

Skewness: It is the measure of the symmetry of the EEG data in the time domain [175,176] which is defined as

$$Skewness = \frac{E[x(n)-\mu^3]}{\sigma^3} \quad (3.7)$$

where μ and σ are mean and standard deviation, E is the statistical expectation.

Root mean square: Root Mean Square (RMS) is a statistical measure of the magnitude of a varying quantity. It is the square root of the arithmetic mean of the squares of the original values [176].

$$RMS = \sqrt{\frac{x_1^2+x_2^2+x_3^2+\dots+x_n^2}{n}} \quad (3.8)$$

where, $x_1, x_2, x_3, \dots, x_n$ are values of n samples of original values.

Energy: Energy is defined as the area under the squared magnitude of the considered signal [176].

$$E_s = \sum_{-\infty}^{+\infty} |x(n)|^2 \quad (3.9)$$

where, E_s is the energy of the signal.

Power spectral density: Power Spectral Density (PSD) measures the average power is distributed as a function of the frequency [175,176].

$$PSD_{fb} = \frac{1}{N} \sum_{t_1}^{t_2} \sum_{f_1}^{f_2} P(t, f) \quad (3.10)$$

where, P is the spectral power at time t (from t_1 to t_2), and frequency f (f_1 and f_2 are the frequency range of the desired EEG frequency band (fb)).

Correlation: Correlation is a measure of the strength of similarity between two signals and ranges from -1 to +1 [162]. It is defined as

$$correlation = \frac{\Sigma(X-\bar{X})(Y-\bar{Y})}{\sqrt{\Sigma(X-\bar{X})^2(Y-\bar{Y})^2}} \quad (3.11)$$

where, \bar{X} and \bar{Y} are the mean value of the X and Y , respectively.

3.3 Uncertainty Assessment in Cognitive Load

Players need to divide attention in complex dynamic situations. These situations have limited or incalculable information and the predicted outcome is very uncertain within the scope of cognitive skills. The high uncertain situations exert more cognitive load on the brain, and it is very difficult to maintain a constant level of attention. If the cognitive load is more than the capacity of the brain, then performance may breakdown and failing to accomplish the task. The uncertainty in the cognitive skill's performance keeps on increasing with variation in cognitive load. The target of repetitive exercise through computerized cognitive training is to overcome complex situations and reduce the cognitive load [154,177]. Thus, continuous cognitive training can reduce the uncertainty in behavior outcomes [21]. So, it is very important to monitor the uncertainty in tasks with varying cognitive load, which will indicate its effectiveness as a training model. All the cognitive processes are held in the brain, and variation in cognitive load can be analyzed using EEG. The beta frequency band of EEG is related to the attentional processes [35]. It is also important to identify the cortex region which is activated in the cognitive training task. Here, the relation between cognitive load and uncertainty in the beta frequency of EEG was explored. The variation in the signal for all the channels was calculated to identify the activated brain region.

3.3.1 Participants

Twenty-five football players (age 18-23 years, mean age 20.63 ± 1.69 years) were chosen for the study. Participants were selected as per the procedure mentioned in section 3.2.1. To establish a participant group, a preliminary cognitive testing session was conducted before the start of the experiment. During this testing, cognitive performance was measured in a d2 attention test

3.3.2 Task Procedure and Measure

Four levels with the varying cognitive load of MOT were designed. In four levels, the number of target circles varies from 2 to 5; 2 targets (in Level 1), 3 targets (in Level 2), 4 targets (in Level

3), and 5 targets (in Level 4) among 6 similar distractors. Each participant performed 30 trials of each level. Average performance accuracy(%APA)was calculated to evaluate the performance of participants in the task [Equation (3.12)]. The %APA was calculated in four levels of the experiment. One-way ANOVA was used to examine the significant difference between the four experimental conditions. Figure 3.14 explained the summarized methodology used in the present research work.

$$\%APA = \frac{\text{number of correct trials}}{\text{total number of trails}} \times 100 \quad (3.12)$$

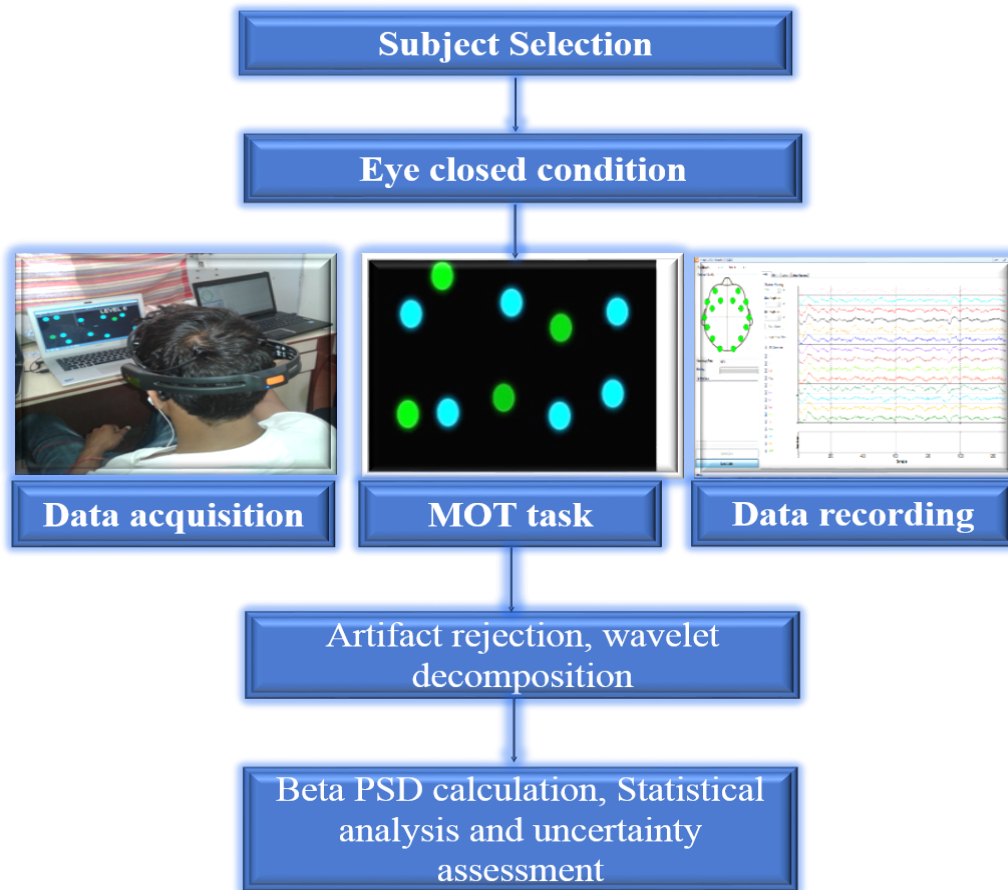


Figure 3.14 Summarized methodology

3.3.3 EEG Data Acquisition and Analysis

EEG signals were recorded using EmotivEpoс+ and processed in EEGLAB (as described in sections 3.2.3 and 3.2.4). ICA using infomax and wavelet transform using bior3.1 wavelet (see section 4.1) was applied to remove the artifacts. Artifact free signal was decomposed using wavelet transform to extract the EEG sub frequency bands; delta, theta, alpha, beta, and gamma.

PSD played a very important role in identifying the relation between cognitive activities and EEG frequency bands. Welch's method was used to calculate the PSD of the beta frequency band [178]. The beta frequency band is more associated with wakefulness and mental activities. In a cognitive enhancement study, beta band power demonstrated significant relation between eye closed condition and brain activities in the MOT task [34]. The analysis of cognitive load was done by comparing baseline condition and cognitive levels of the MOT task for EEG data. In the baseline condition, EEG was recorded for each participant in eye closed condition for 2 minutes. After that, EEG was recorded for each cognitive load condition. The percentage relative PSD (%RPSD) of the beta band was calculated to analyze the uncertainty in the EEG data. It is defined as the ratio of the beta PSD to the total PSD (sum of the all band PSDs) and multiplies by 100. It is expressed by the formula shown in Equation (3.13).

$$\%RPSD = \frac{\text{beta band PSD}}{\text{total PSD}} \times 100 \quad (3.13)$$

Initially, the baseline value was calculated for each channel for %RPSD in the eye closed condition. In all 14 channels and four cognitive load conditions, change in %RPSD was measured by subtracting subsequent averaged values from the baseline value. Thereafter, the work was conducted for the 30 trials on the 25 subjects. Uncertainty was assessed for both sources of the variation in EEG; due to several trials (u_t) and subjects (u_s). Estimated standard deviation (std) is defined as the standard uncertainty [179,180]. The uncertainty (u) was calculated by Equation (3.14). The combined uncertainty (u_c) was determined by Equation (3.15). A t-test was used to check the level of significance between the baseline and cognitive levels.

$$u = \text{std}/\sqrt{n} \quad (3.14)$$

$$u_c = \sqrt{u_t^2 + u_s^2} \quad (3.15)$$

3.4 Individual differences in cognitive load assessment

Several studies have reported the relation between cognitive workload and spectral power of brain waves in particular [35,36,156,181]. Evidence of the relation between theta and cognitive workload has been summarized in earlier studies[35,182].The solicitation of task requirement is linked with synchronization of theta spectral power and demonstrates the activation of frontal regions. Several studies linked front-parietal theta power to working memory and higher theta

spectral power represents lower memory capacity[35,157,183,184]. However, in some studies, The increasing cognitive load at the same task demonstrated inconsistent patterns of spectral theta increase[185–187]. The alpha desynchronization with increased difficulty and memory load has also been presented[35,188]. Alpha desynchronization has also been indicated as a biomarker of arousal and resource allocation[189].Alpha spectral power also fell as the pressure on the brain increased over time [190].The alpha power decline is mainly associated with the parietal cortex region. These earlier studies focused on the relation between theta and alpha spectral powers with the cognitive workload, whereas beta spectral power is also linked with inattention. The current study examined the relation between cognitive workload and EEG (alpha, beta, and theta) frequency bands.

The lack of coherence patterns in spectral powers of EEG frequency bands has been seen possibly due to two reasons. The first reason might be because earlier studies have evaluated the workload in a single trial of the task. Secondly, every individual has distinct working memory capacity and could not control the attentional processes in the same pattern. Here, both the concerns were taken into account.

In the present study, both concerns have been taken into account. This study is the extension of the experiment performed in section 3.3. Based on the performance in d2 test, participants were divided into three clusters; high, medium, and low performers. It is hypothesized that theta band would synchronize with the increase in workload and this would be higher for low performers. As the participants need to store more items in working memory with an increase in difficulty, it is expected that alpha and beta power would decrease.

3.4.1 Participants

Participants performed a d2 attention test which is a paper-pencil cancellation test [147,148]. Participants were asked to track target items (d with 2 dash lines) among distracter items. The test consists of 14 rows and 47 characters in each row. Participants were directed to cancel the target items with a time limit of 20 seconds (per row) without breakage from left to right. According to the results, a concentration performance measure has been used to split participants into three groups. Ward method was used to divide the participants into three clusters[36].

3.4.2 Task Procedure

The same procedure performed in section 3.3.2 was followed.

3.4.3 EEG signal processing

EEG signals were recorded using Emotiv Epoc+ and processed in EEGLAB using the procedure which is mentioned in section 3.2.4. The clean signal was decomposed using wavelet transform and beta, alpha, and theta frequency bands were segregated. Welch method was used to calculate the PSD of each frequency band. ANOVA (3 groups and 4 levels) were used to analyze the statistical significance of cognitive load.

3.5 Cognitive Skills Enhancement through Cognitive Training

This research aims to look at the impact of cognitive training on the cognitive functions of sports players. To study the influence of the MOT task on cognitive functions, participants performed the task on the computer system. To test the effectiveness of the MOT training program on cognitive skills, a pre-test and post-test cohort case study were designed. It includes pre-post psycho-physiological measurement of the cognitive functions. EEG data was collected while performing the first and last training session. Statistical tests (t-test, ANOVA) were used to analyze the results of the psychological tests as well as EEG data.

3.5.1 Participants

To establish participant groups, a preliminary cognitive testing session was conducted before the start of the experiment. Before starting the experiment, cognitive performance was measured using the Sport Competition Anxiety Test (SCAT). Participants scored below average were rejected for participation in the study. The remaining procedure was repeated as per section 3.2.1. The participants had no previous experience of cognitive training.

According to these parameters, 27 university football players (age between 18-23 years, mean age 19.51 ± 1.08 years) and 10 education matched non-athlete (age between 18-24 years, mean age 19.18 ± 2.21 years) were enrolled (Table 3.4). The non-athletes were university students who never participated in football training or any other sports. Out of 27 football players, two groups of participants were created. 17 players were randomly selected for the cognitive training named as an active group and no training was given to the remaining 10 players designated as a passive

group. The group of non-athletes was selected as the control group. All the participants had no history of neurological disease. Participants were informed about the MOT task, psychological tests, and EEG data recording procedure before starting of the experiment.

Table 3.4 Details of participants

Groups		No. of Participants	Average age	Standard Deviation	Playing Experience
Players	Active group	17	19.51	1.08	30 matches
	Passive group	10			
Non-Players	Control group	10	19.18	2.21	0

3.5.2 Task Stimuli and Procedure

The stimuli were presented on a computer screen with a resolution of 1366×768 pixels and a size of 34×19 cm. Initially, participants were seated in an adjustable chair and asked to find a snug position from which they would not move. The position of the computer screen was adjusted to maintain an 80 cm distance from the participants. The experiment was conducted in a noise-free, dim-lit, and closed room environment. Before starting the experiment, participants were made habituated with the computer controls for the MOT task. Before starting the experiment, participants were seated for 2-minutes in eye closed condition and EEG data was recorded while playing MOT (section 3.1). The overall experiment was divided into three steps, pre-measurement, training intervention and post-measurement, and post2 measurement. Figure 3.15 describes the detailed methodology.

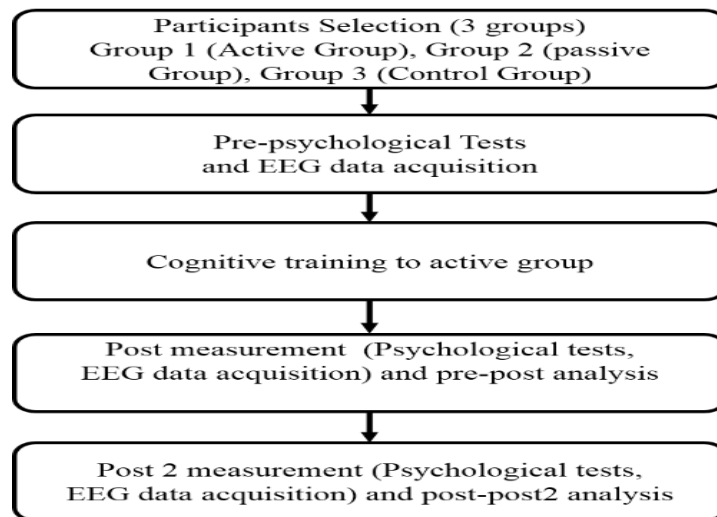


Figure 3.15 Block diagram represents the detailed methodology

3.5.3 Pre measurement

Psychological testing and physiological measurement of each participant were performed on the very first day of the experiment. All the participants participated in psychological tests and EEG data were collected (explained in section 3.2.3) while playing the MOT training model.

3.5.3.1 Psychological Performance Measures

The psychological test included in testing to evaluate the player's capacity of working memory, and attention. Before the testing, a brief introduction about the tests and procedure was given to participants. Then participants performed the MOT task on the computer screen during which EEG data was acquired. To measure the cognitive skills, an ecological test derived from the behavior assessment of the Psychology Experiment Building Language (PEBL) test battery and Cogstate test battery was used.

a) *PEBL Battery Tests*

Corsi Test: The test was used to measure the working memory capacity. The Corsi test consists of a set of nine identical blocks which were irregularly positioned on the screen (Figure 3.16). A series of blocks at a rate of one block per second was presented by the computer. Participant's task was to remember the same blocks in their order of presentation. When the sequence was finished then participants needed to click on each block in the same sequence. The test was started with a sequence of two squares and participants got two tries for each sequence length. The sequence was increased by one whenever at least one of the two sequences was correct. Also, three practice trials were performed by each participant to become familiar with the test. Two measures, memory span, and total score were calculated from this test. Memory span is the length of the last correctly reproduced sequence. The total score is the multiply of the number of correct trials and memory span [139,143,191]. A high score of memory span and total score represents better performance.

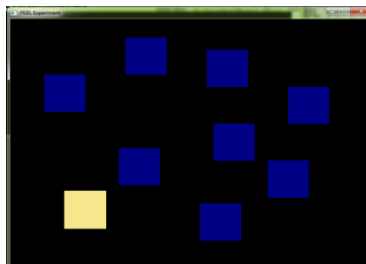


Figure 3.16 Corsi test

Dspan Test: It is a working memory test in which a sequence of digits (one at a time) was presented on the screen (Figure 3.17 (a) and (b)). The participant task was to remember the sequence of digits. At the end of the sequence, participants were asked to type the sequence of digits in the same order. If the participant forgets any digit, then an empty space was filled by the ‘-’ key but led incorrect response. Any mistake could be corrected by the ‘backspace’ key. The test was started with a sequence of four digits. If the participants were able to recall the sequence correctly, then the next sequence was increased by one digit. Whereas, incorrect responses decreased the length of the sequence by one digit. The response time was calculated from each participant. Response time was calculated by dividing the total time taken to complete the task and the number of stimuli. A low response time represents better performance [140,141].



Figure 3.17 (a) Dspan test response window (b) representing ‘correct’ response

Stroop Test: It assesses the attentional ability to inhibit cognitive interference, which occurs when the processing of a stimulus feature affects the simultaneous processing of another attribute of the same stimulus. Initially, a screen was displayed with a colored word in the center, and four respond to key options from 1 to 4. The test was performed in two parts with different word names and word colors. In the first part, the participant's task was to identify the word name and ignore the ink color, whereas, in the second part, the participant needed to identify the color of the word and ignore the word name (Figures 3.18 (a) and (b)). Response time was calculated as the measure of the stroop test. The total time taken to complete the task divided by the number of stimuli was used to calculate response time [149].

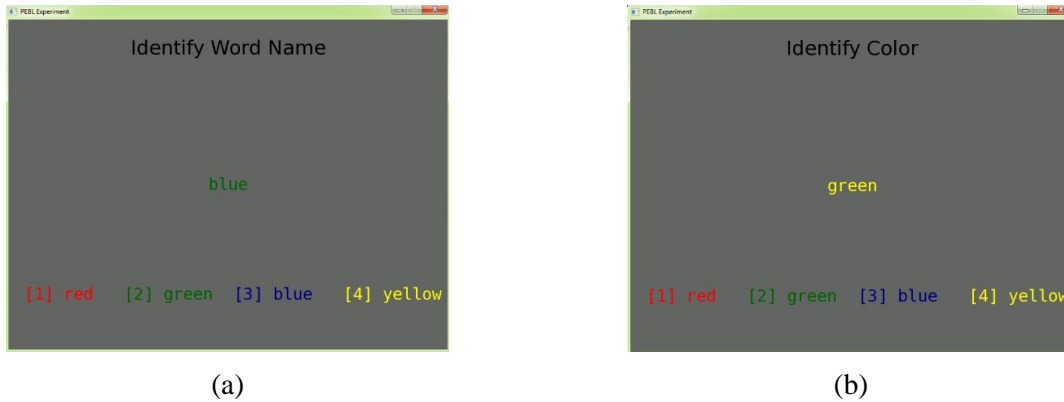


Figure 3.18 Stroop test (a) different word color and word name, identify the word name, (b) different word color and word name, identify the word color

Continuous Performance Test: Continuous Performance Test (CPT) is used to measure attention. Participants were asked to respond to the stimuli, which were presented on the screen (Figure 3.19). The participant was asked to press the spacebar as quickly as possible after each letter and do not respond to the letter 'X'. The test was conducted for approximately 14 minutes. Response time was calculated by dividing the total time taken to complete the task and the number of stimuli [135,151].



Figure 3.19 Screenshot represents CPT

b) Cogstate battery tests

Two Back Test: Two Back (TWOB) Test is a working memory test that was performed on the computer screen and continued for 4 minutes. It worked on the principle of the n-back test paradigm. In this test, participants were asked to remember the card which was presented on the center of the screen. Participants were supposed to follow the instruction: "Is the card the same as that shown two cards ago?". The participant must decide whether the card was the same as the card shown two cards previously. If the card was the same, then the participant was asked to

press “K for yes” otherwise “D for No” (Figures 3.20 (a) and (b)). Participants were encouraged to respond as quickly as they can be. Accuracy was calculated as the measure of this test. Accuracy is the multiplication of 100 with the ration of the correct response and total stimuli [144,145].



Figure 3.20 TWOB test. (a) shows the instructions (b) shows the test window

IDN Test: It measures attention using a choice reaction time paradigm. The on-screen instructions ask: “Is the card red?”. A playing card was presented face down in the center of the screen. The card flips over, so it was face up. As soon as it flipped over, the participant must decide whether the card was red or not (Figures 3.19 (a) and (b)). If it was red, the participant should press “K for Yes”, otherwise “D for No”. The participants were encouraged to work as quickly as they can be. Accuracy was calculated as the measure of this test. Accuracy is the multiplication of 100 with the ration of the correct response and total stimuli [152].

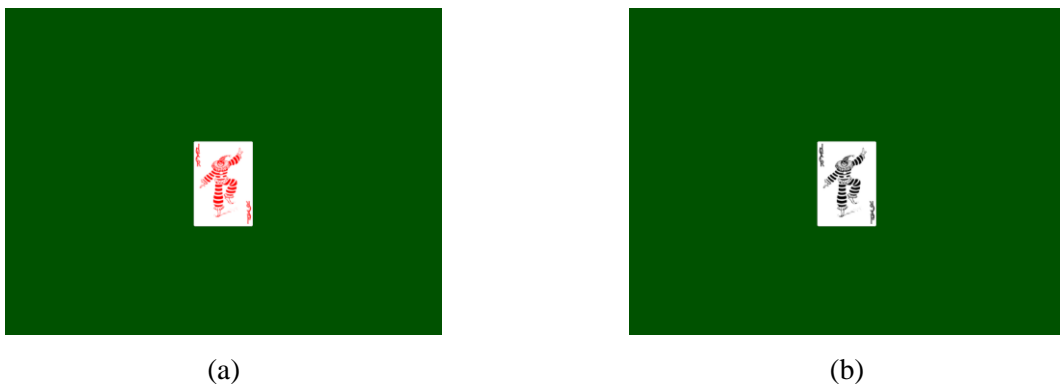


Figure 3.21 IDN test. (a) red card (b) black card

3.5.3.2 Physiological Measure

EEG signals were recorded using EmotivEpoC+ (described in section 3.2.3) and processed (described in section 3.2.4). Three sub frequency bands of EEG signal were extracted, *i.e.*, theta, alpha, and beta band. Two measures were calculated to extract the information from the recorded data, *i.e.*, PSD (Equation 3.10) and partial directed coherence (PDC).

The connectivity of different nodes within neuronal networks was measured and analyzed. There are many methods to measure the connectivity of brain regions based on EEG signals. Several methods for connectivity analysis have been reported using the temporal dynamics of brain sources that were reconstructed from scalp EEG signals [192]. Two types of brain connectivity are explained in the literature: functional and effective. Functional connectivity is based on different time and frequency domain methods [193]. Recently, PDC has been generalized to time-varying and vector-based multivariate analyses[194]. Based on the methods of connectivity studies, PDC provides a suitable explanation for EEG channels related to cognitive activities and cognitive load.

PDC is a measure of brain connectivity, used to find the interactions between two electrode locations to measure the strength between them. Suppose, two signals are x_1 and x_2 with time observations $x_1(t)$ and $x_2(t)$ where $t = 1, 2, 3 \dots n$. The interactions between the two signals were described with a bivariate autoregressive model (ARX).

$$x_1(t) = \sum_{k=1}^q y_{11,k} x_1(t-k) + \sum_{k=1}^q y_{12,k} x_2(t-k) + e_{x_1}(t) \quad (3.16)$$

$$x_2(t) = \sum_{k=1}^q y_{21,k} x_1(t-k) + \sum_{k=1}^q y_{22,k} x_2(t-k) + e_{x_2}(t) \quad (3.17)$$

The linear ARX models (3.11) and (3.12) can be rewritten as in matrix form and mapped to the frequency domain by Fourier transform:

$$\begin{pmatrix} Y_{11}(f) & Y_{12}(f) \\ Y_{21}(f) & Y_{22}(f) \end{pmatrix} \begin{pmatrix} X_1(f) \\ X_2(f) \end{pmatrix} = \begin{pmatrix} E_{x_1}(f) \\ E_{x_2}(f) \end{pmatrix} \quad (3.18)$$

$$\pi_{x_1 \rightarrow x_2}(f) = \sum_{k=1}^q y_{21,k} x_1(t-k) - \frac{Y_{21}(f)}{\sqrt{|Y_{11}(f)|^2 + |Y_{21}(f)|^2}} \quad (3.19)$$

Here, $\pi_{x_1 \rightarrow x_2}$ describes the relative coupling strength of the interaction from a signal source such as $x_1(t)$ to some other signal such as $x_2(t)$, as compared to all the connections of the source to other signals. For a bivariate system, the directed interaction is described by Y_{21} and it is

normalized by all the x_1 related terms in the ARX models (such as Y_{11} and Y_{21}). The magnitude of PDC lies between zero and one.

3.5.4 Training Intervention, Post and Post2 Measurement

The previous research suggested that the 20 to 30 minutes of cognitive training was good for the brain health and observed mid fatigue after 30 minutes [34]. Also, Memory enhancement appeared to be sustained after a 3-month no-contact follow-up period [48]. The results indicated that the training group showed no significant change in memory function after training and at 3-month follow-up. The participants of the active group performed 20 training sessions over four weeks. Training sessions were scheduled each day except weekends which led to five sessions in a week. In each session, the developed cognitive training model (section 3.1) was played for half an hour. A total of 10 hours of training was given to the participants. Players (active and passive group members) were instructed to continue their soccer practice during the cognitive training period. No instruction and training were provided to participants of the control group. After the completion of the cognitive training program, post-measurement of the cognitive skills using psychological tests and EEG data were performed. In the post-measurement, the same procedure was followed as pre-measurement. T-test and analysis of variance (ANOVA) were performed to analyze the effect of cognitive training. Thereafter, all participants performed the post2 measurement after a retention interval of three months. The post2 measurement aimed to analyze the longevity of cognitive training. During this period, no cognitive training was given to the active group.

In this chapter, the detailed methodology was described in four parts. First, it explained the design of the cognitive training model. Second, it described the participant selection, EEG data acquisition, and processing with the procedure used to obtain the optimal wavelet. Third, it described the procedure used to assess the cognitive load. Fourth, it showed the procedure used to evaluate the individual performance with varying cognitive load. Fifth, it explained the procedure used to obtain the influence of the cognitive training model on cognitive skills.

CHAPTER 4

Results and Discussion

The visual and quantitative analyses of the experimentation are discussed in this chapter.

4.1 Wavelet Selection

The results of the EEG pre-processing and wavelet selection are presented in this section. Firstly, four features, PSD, RMS, skewness, and energy of each channel were calculated for the raw signal and clean signal (D1). Figure 4.1 shows the plot between the average PSD of D1 and wavelet numbers. The average PSD is the average of the PSD of the 14 channels of the D1. Each wavelet has been assigned a number (Table 3.3). It is observed that the wavelet bior3.1 gives maximum PSD (7.2×10^3). The average of the PSD is also calculated for the raw signal (R) of the 14 channels. A statistical t-test is applied between the PSD of the D1 and R of 25 participants for each channel. The statistical significance ($p < 0.05$) is observed between the PSD of the two signals for each channel. It was observed for all 109 wavelets and found significant.

Similarly, RMS is calculated for the D1 and R signals of each channel for each subject. Figure 4.2 shows the plot between the average RMS and wavelet numbers. The wavelet bior3.1 gives maximum RMS (14.81) out of 109 wavelets. The statistical difference using t-test is calculated between the RMS of the D1 and R for each channel. A significant difference ($p < 0.05$) between RMS of two signals was observed for all wavelets. The skewness of 14 channel EEG signals is also calculated for the D1, and R. Figure 4.3 demonstrates the plot between the average skewness and wavelet numbers. The wavelet rbior3.1 gives minimum skewness (0.08753) out of 109 wavelets, and bior3.1 indicates the second best. The statistical significance ($p < 0.05$) is observed between the skewness of D1 and R of each channel. The energy obtained from the D1 is represented in Table 4.1(a-d) for the 109 wavelets. T-test shows the significant difference ($p < 0.05$) between the energy of D1 and R. It is found significant for all 109 wavelets. The statistical difference between the four features showed the dissimilarity between raw and clean signals. Whether, the artifacts are effectively removed, or not, from the raw signal are determined by adding the artificial noise in the clean signal (D1) and again denoised signal (D2) using the same process.

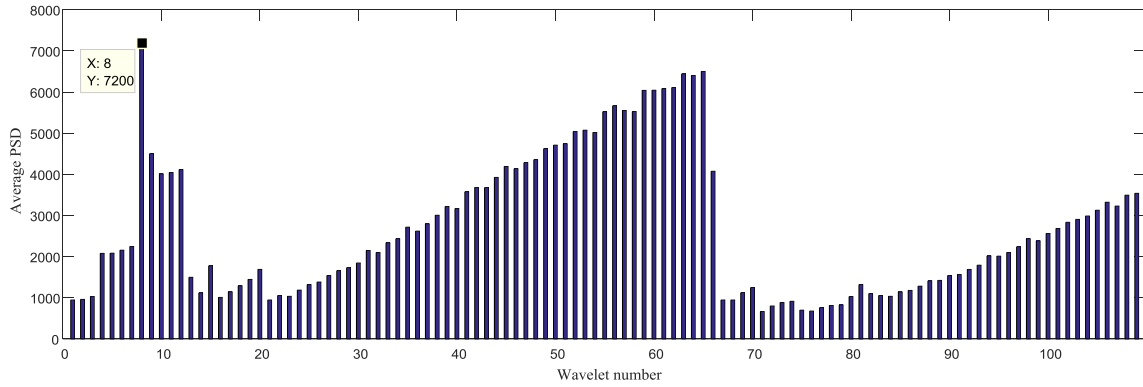


Figure 4.1 Comparative plot average PSD of D1 vs wavelet. [Horizontal axis shows the number of wavelets as per in Table 3.3. Wavelet at number X= 8 (bior3.1) showed the maximum average PSD]

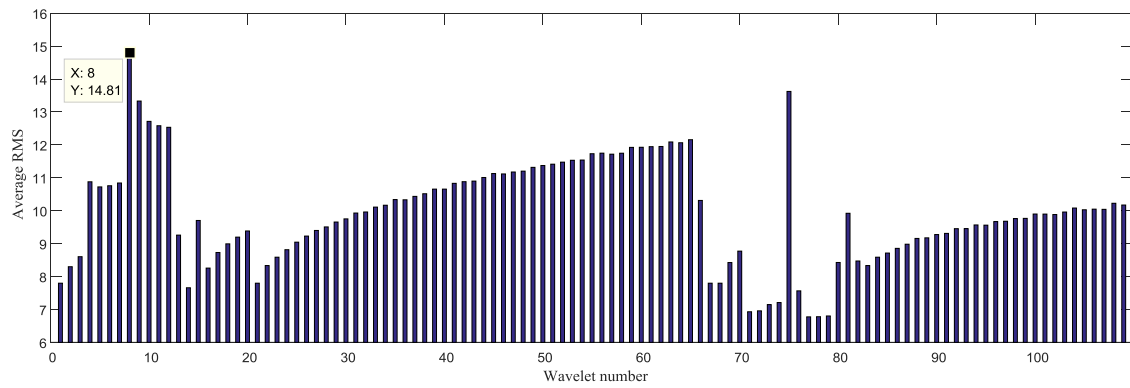


Figure 4.2 Comparative plot average RMS of D1 vs wavelet. [Horizontal axis shows the number of wavelets as per in Table 3.3. Wavelet at number X= 8 (bior3.1) showed the maximum average RMS]

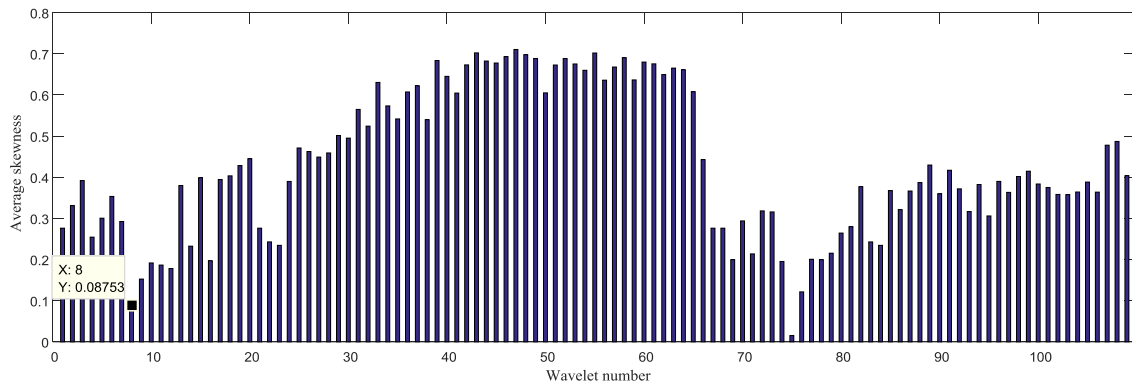


Figure 4.3 Comparative plot average skewness of D1 vs wavelet. [Horizontal axis shows the number of wavelets as per in Table 3.3. Wavelet at number X= 8 (bior3.1) showed 2nd minimum average skewness

The energy retains and correlation between D1 and D2 for each channel are calculated to determine the effectiveness of the denoising procedure. The energy retain is the ration of energy of two signals and correlation shows the similarity between two signals Table 4.1 (a), (b), (c) and

(d) show the average energy retain and correlation values of the 109 types of the wavelets. Table 4.1 (a) demonstrates the values of biorthogonal and reverse biorthogonal wavelet families. In the biorthogonal family, bior3.1 shows the maximum energy retain (0.965) and correlation (0.9975), whereas, in the reverse biorthogonal family, rbior5.5 shows the maximum energy retain (0.917) and rbior1.1 shows the highest correlation (0.9969). Table 4.1 (b) shows the values of daubechies wavelet family. The maximum energy retains (0.894), and the highest correlation (0.9969) is shown by db45 and db1, respectively. Table 4.1 (c) displays the values of symlet wavelet family. The energy retains and correlation for most of the symlet wavelets are nearly similar, *i.e.*, 0.889 and 0.9967, respectively. Table 4.1 (d) depicts the values of Coiflets, Haar, and DMeyer family wavelets. It is observed that coif5 shows the maximum energy retain (0.888), and haar wavelets depict the highest correlation (0.9969). The maximum correlation and energy retain are obtained for the bior3.1 wavelet out of 109 wavelets. It suggests that bior3.1 shows the highest similarity between the two signals and efficiently removes the artificially added noise in the signal.

Table 4.1 (a) Energy ratio and correlation between D1 and D2 of Biorthogonal and Reverse Biorthogonal wavelets

Wavelet	Average D2 energy ($\times 10^7$)	Average D1 energy ($\times 10^7$)	D2/D1	Correlation between D1 and D2	Wavelet	Average D2 energy ($\times 10^7$)	Average D1 energy ($\times 10^7$)	D2/D1	Correlation between D1 and D2
bior1.1	4.138	4.775	0.867	0.9969	rbior1.1	4.132	4.775	0.865	0.9969
bior1.3	4.652	5.256	0.885	0.9967	rbior1.3	4.949	5.695	0.869	0.9965
bior1.5	5.026	5.644	0.891	0.9966	rbior1.5	5.505	6.302	0.874	0.9963
bior2.2	9.131	9.988	0.914	0.9964	rbior2.2	3.340	3.959	0.844	0.9962
bior2.4	8.878	9.668	0.918	0.9965	rbior2.4	3.609	4.273	0.844	0.9964
bior2.6	9.016	9.781	0.922	0.9965	rbior2.6	3.944	4.668	0.845	0.9964
bior2.8	9.207	9.957	0.925	0.9965	rbior2.8	4.053	4.795	0.845	0.9964
bior3.1	20.892	21.650	0.965	0.9975	rbior3.1	8.165	10.880	0.750	0.9727
bior3.3	16.751	17.608	0.951	0.9960	rbior3.3	3.930	4.846	0.811	0.9934
bior3.5	14.711	15.490	0.950	0.9961	rbior3.5	3.557	4.312	0.825	0.9949
bior3.7	14.557	15.309	0.951	0.9962	rbior3.7	3.623	4.379	0.827	0.9952
bior3.9	14.452	15.163	0.953	0.9962	rbior3.9	3.596	4.355	0.826	0.9953
bior4.4	6.232	7.067	0.882	0.9964	rbior4.4	4.949	5.595	0.884	0.9967
bior5.5	4.507	5.386	0.837	0.9961	rbior5.5	6.556	7.147	0.917	0.9968
bior6.8	7.061	7.917	0.892	0.9965	rbior6.8	5.042	5.736	0.879	0.9966

Table 4.1 (b) Energy ratio and correlation between D1 and D2 of Daubechies wavelets

Wavelet	Average D2 energy ($\times 10^7$)	Average D1 energy ($\times 10^7$)	D2/D1	Correlation between D1 and D2	Wavelet	Average D2 energy ($\times 10^7$)	Average D1 energy ($\times 10^7$)	D2/D1	Correlation between D1 and D2
db1	4.140	4.775	0.867	0.9969	db24	13.224	14.868	0.889	0.9965
db2	4.920	5.611	0.877	0.9967	db25	13.919	15.643	0.890	0.9965
db3	4.952	5.613	0.882	0.9967	db26	13.465	15.143	0.889	0.9965
db4	5.549	6.266	0.886	0.9967	db27	13.803	15.541	0.888	0.9965
db5	6.078	6.869	0.885	0.9966	db28	13.961	15.712	0.889	0.9965
db6	6.449	7.262	0.888	0.9966	db29	14.696	16.514	0.890	0.9965
db7	6.979	7.858	0.888	0.9966	db30	14.801	16.639	0.890	0.9965
db8	7.251	8.161	0.889	0.9966	db31	15.123	17.002	0.889	0.9965
db9	7.591	8.548	0.888	0.9966	db32	15.731	17.681	0.890	0.9965
db10	7.766	8.734	0.889	0.9966	db33	15.534	17.485	0.888	0.9965
db11	8.786	9.872	0.890	0.9966	db34	15.442	17.385	0.888	0.9965
db12	8.502	9.571	0.888	0.9966	db35	17.307	19.425	0.891	0.9965
db13	9.348	10.510	0.889	0.9966	db36	17.326	19.468	0.890	0.9965
db14	9.379	10.558	0.888	0.9966	db37	16.763	18.854	0.889	0.9965
db15	10.262	11.533	0.890	0.9966	db38	16.420	18.481	0.889	0.9965
db16	9.799	11.015	0.890	0.9966	db39	18.500	20.761	0.891	0.9965
db17	10.475	11.777	0.889	0.9965	db40	18.056	20.314	0.889	0.9965
db18	10.542	11.877	0.888	0.9965	db41	18.077	20.322	0.890	0.9965
db19	11.373	12.785	0.890	0.9965	db42	18.245	20.492	0.890	0.9965
db20	11.373	12.790	0.889	0.9965	db43	18.995	21.356	0.889	0.9965
db21	12.461	14.016	0.889	0.9965	db44	18.599	20.947	0.888	0.9965
db22	12.410	13.944	0.890	0.9965	db45	15.974	17.869	0.894	0.9965
db23	12.677	14.233	0.891	0.9965					

Figure 4.4 is plotted between the classification accuracy and wavelet numbers. The calculated features (skewness, PSD, RMS, and energy) are fed to the SVM classifier for training and testing. The five-fold cross-validation procedure is applied to the SVM. In the five-fold procedure, the complete data set is divided into five parts, and each part contains 20% information of the dataset. The training of the SVM is performed by 80% of the data and the remaining 20% is selected for the testing of the classifier. This process is repeated for each part

of the dataset and average classification accuracy is calculated. This is applied for all 109 wavelets, and bior3.1 shows the maximum classification accuracy (91.68%).

Table 4.1 (c) Energy ratio and correlation between D1 and D2 of Symlets wavelets

Wavelet	Average D2 energy ($\times 10^7$)	Average D1 energy ($\times 10^7$)	D2/D1	Correlation between D1 and D2	Wavelet	Average D2 energy ($\times 10^7$)	Average D1 energy ($\times 10^7$)	D2/D1	Correlation between D1 and D2
sym2	4.919	5.611	0.877	0.9967	sym16	7.830	8.820	0.888	0.9966
sym3	4.950	5.613	0.882	0.9967	sym17	8.126	9.162	0.887	0.9966
sym4	5.124	5.809	0.882	0.9966	sym18	8.190	9.220	0.888	0.9966
sym5	5.480	6.192	0.885	0.9967	sym19	8.658	9.748	0.888	0.9966
sym6	5.644	6.377	0.885	0.9966	sym20	8.699	9.802	0.887	0.9966
sym7	6.265	7.050	0.889	0.9966	sym21	8.675	9.787	0.886	0.9966
sym8	6.129	6.905	0.888	0.9966	sym22	9.030	10.176	0.887	0.9966
sym9	6.494	7.317	0.887	0.9966	sym23	9.394	10.583	0.888	0.9966
sym10	6.455	7.273	0.888	0.9966	sym24	9.434	10.623	0.888	0.9966
sym11	6.959	7.832	0.889	0.9966	sym25	9.683	10.922	0.887	0.9966
sym12	6.997	7.879	0.888	0.9966	sym26	9.613	10.840	0.887	0.9966
sym13	7.455	8.402	0.887	0.9966	sym27	10.249	11.547	0.888	0.9966
sym14	7.343	8.275	0.887	0.9966	sym28	10.147	11.445	0.887	0.9966
sym15	7.791	8.771	0.888	0.9966					

Table 4.1 (d) Energy ratio and correlation between D1 and D2 of Coiflets, Haar, DMeyer

Wavelet	Average D2 energy ($\times 10^7$)	Average D1 energy ($\times 10^7$)	D2/D1	Correlation between D1 and D2	Wavelet	Average D2 energy ($\times 10^7$)	Average D1 energy ($\times 10^7$)	D2/D1	Correlation between D1 and D2
coif1	4.545	5.211	0.872	0.9967	dmey	10.844	12.233	0.886	0.9966
coif2	5.205	5.912	0.880	0.9967	haar	4.138	4.775	0.866	0.9969
coif3	5.711	6.455	0.885	0.9966					
coif4	6.171	6.957	0.887	0.9966					
coif5	6.867	7.733	0.888	0.9966					

The removal of artifacts from the EEG signal is very important. These artifacts may mimic brain cognitive activities and may also overlap the EEG frequency bands. There are several types of research on artifact removal in higher density systems, and the challenge still lies when we have

a small number of channels. In this section, the combination of ICA and WT has been applied to denoise the EEG signals. This study was carried out for the 14 channel EEG system. This method can be used for high dense systems. It may be noted that the quality of the ICA relies on the pre-processing (dimensionality reduction in dense EEG). The artificial noise was added to the denoised signal and again removed noise using the same procedure. The high correlation and energy ration between these two signals represented that the efficacy of the artifact removal procedure. The investigation was done using wavelets from seven different families and information varies between all the wavelets. In contrast, SVM offers a reliable solution by estimating an optimum separating hyper plane using training data from both artifactual and non-artifactual signals. We used a linear kernel SVM in this work because it has less computational demand than other methods.

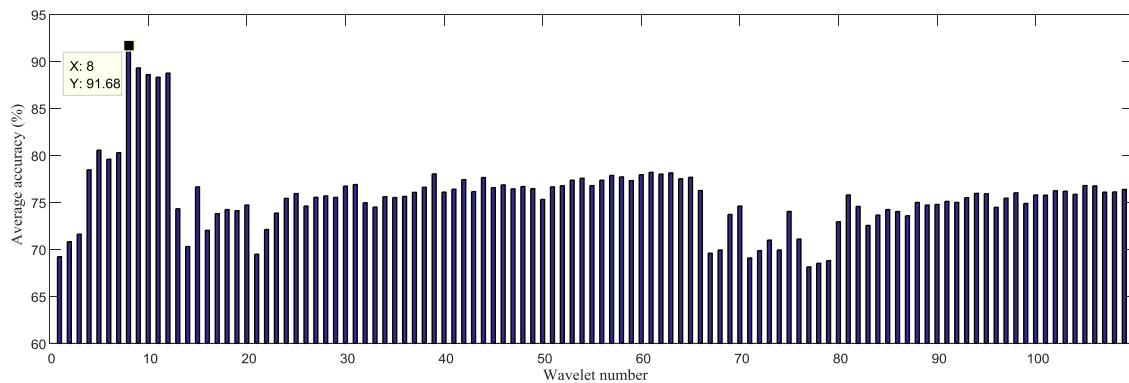


Figure 4.4 Comparative plot of average accuracy vs wavelet. [Horizontal axis shows the number of wavelets as per in Table 3.3. Wavelet at number X= 8 (bior3.1) showed the maximum accuracy]

Wavelet selection is a very crucial step to denoise, decompose and feature extraction of EEG signal. Several researchers used the different wavelets from daubechies family to denoise the EEG signals like db2, db3, db4, db5, sym7, coif3, coif4 etc. [160,162,171,176,195]. The wavelet db4 was used for epileptic signals [196] and db2 was found more appropriate for EEG smoothing [197]. The properties of the signal and wavelet function should be matched. The experiment was conducted using 109 wavelet functions. Four features were calculated to identify the optimal wavelet. These features defined the different characteristics of the signal. These features were used in training and testing the SVM for the classification between raw signal and denoised signal. A large variation in the classification accuracy was found from 68.13% to 91.68%

between the wavelets. It was identified that the bior3.1 had the most similar characteristics of the signal.

4.2 Uncertainty Assessment in Cognitive Load

The result analysis of this experiment is divided into two parts. The first part describes the behavioral performance of the participants in terms of the %APA. In the second part, PSD was calculated to analyze the EEG data for the uncertainty analysis. ANOVA and t-test were employed to identify the statistically significant differences between the results.

4.2.1 Task Performance Analysis

Figure 4.5 provides information about the %APA of participants for four levels of task and shows a decreasing trend. In the first level, %APA is observed higher than the other levels of the experiment. The %APA varies from 98.7 ± 3.1 to $81.8 \pm 18.73\%$ in four levels of the experiment. L1's %APA is $98.7 \pm 3.1\%$, higher than L2 by 2.3%. Then, it decreases to 7.3% in L3 and continues to decline by 8.3% in L4. Also, the standard deviation increases with the difficulty of the experiment from 3.1 to 18.73%, which shows more variation in the performance. There is a minor increase in complexity from L1 to L2 because participation in L1 makes the subjects familiar with the task. But L3 and L4 exert more cognitive load on the subjects and cause a rapid decline in performance. The statistical test is applied to results to find the level of significance among four task levels. The results of the one-way ANOVA showed a significant difference in %PA with $F = 10.75$, $p < 0.05$ for them between all levels.

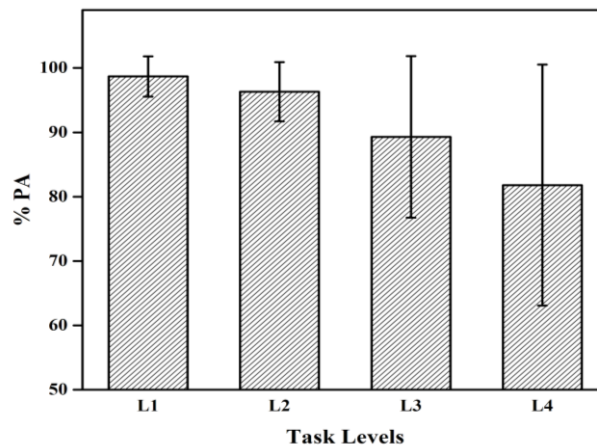


Figure 4.5 Averaged %PA in four levels

4.2.2 EEG and Uncertainty Analysis

The percentage change in the PSD of the beta frequency band was measured by subtracting the average baseline value from the subsequent average values. Tables 4.2 – 4.5 show the variation in averaged PSD in each channel for all four levels of the experiment. The T-test between the PSD of baseline and level was applied to find the statistical difference for each channel and shown by the p-values in each table.

In L1, the value of the averaged %RPSD increases substantially and crosses the baseline value except for FC5 and F4 channels, as shown in Table 4.2. All the channels show a significant ($p < 0.05$) difference between cognitive load and baseline value and vary from - 11.07 to 1.91%. Less variation is seen in the channel location FC5 (1.91%) and F4 (1.29%) than the baseline value, while channel P8 (- 11.08%) shows the maximum variation. These results reveal that the physiological measurement is not uniform at all the channel locations and sensitive to cognitive load on the brain. The examination is carried forward with the assessment of the uncertainty in the data. u_c is the overall estimation of uncertainty in this experiment. The value of u_c ranges from 0.038 to 0.058%. AF4 channel shows the least uncertainty (0.038%) in the experiment, while channel F3 has the highest uncertainty (0.058%).

Table 4.2 Uncertainty estimation in Level 1

Channel	Baseline value (in %)	Change in values (in %)	Subjects variation		Trials variation		Combined Uncertainty (u_c) (%)	p values
			standard uncertainty (%)	Uncertainty (u_s) (%)	standard uncertainty (%)	Uncertainty (u_t) (%)		
AF3	30.83	-2.87	0.133	0.027	0.162	0.030	0.040	0.000
F7	34.17	-1.49	0.125	0.025	0.203	0.037	0.045	0.003
F3	24.17	-6.48	0.225	0.045	0.198	0.036	0.058	0.047
FC5	31.11	1.91	0.198	0.040	0.159	0.029	0.049	0.000
T7	33.69	-3.92	0.161	0.032	0.190	0.035	0.047	0.000
P7	28.92	-6.50	0.154	0.031	0.211	0.039	0.049	0.009
O1	28.56	-5.62	0.113	0.023	0.209	0.038	0.044	0.000
O2	32.12	-2.14	0.112	0.022	0.213	0.039	0.045	0.000
P8	24.27	-11.07	0.143	0.029	0.219	0.040	0.049	0.000
T8	38.01	-2.65	0.152	0.030	0.212	0.039	0.049	0.000
FC6	28.88	-4.96	0.144	0.029	0.202	0.037	0.047	0.000
F4	31.31	1.29	0.165	0.033	0.197	0.036	0.049	0.017
F8	25.82	-7.86	0.119	0.024	0.212	0.039	0.045	0.000
AF4	29.69	-3.61	0.099	0.020	0.175	0.032	0.038	0.000

In next level (L2) of the cognitive load, Table 4.3 shows that the variation in the %RPSD values of each channel is more as compared to L1. The significant percentage average change in the

%RPSD of L2 is observed for each channel and varies from - 3.13 to - 14.51%. In this level, channel F4 (- 3.13%) shows the smallest percentage average change from the baseline, and the maximum change is observed in channel P8 (- 14.51%). The combined uncertainty is also higher than the previous level (0.043–0.064%). In L2, it is observed that the channel AF4 (0.043%) has minimum uncertainty, the same as of level 1. The utmost uncertainty is observed in the channel FC6 (0.064%).

Tables 4.4 and 4.5 show the results of L3 and L4, respectively. In L3, the significant percentage change increases than the previous levels of the task, L1, and L2. F4 (- 6.33%) and AF3 (- 6.34%) show the minimum percentage change in the %RPSD as compared to other channels. Channel F8 exhibits the maximum percentage change, *i.e.*, - 19.46%. Corresponding to L3, the combined uncertainty varies from 0.05 to 0.076%, which is higher as compared to L2. Channel FC5 has shown the lowest uncertainty in this level and P8 has maximum uncertainty, *i.e.*, 0.076%. Channel AF4 showed the least uncertainty in the previous levels and 0.056% uncertainty in this level. Table 4.5 shows the variation in the %RPSD for high-cognitive load task (L4). The percentage change fluctuated from - 8.10 (F4) to - 20.88% (P7). The combined uncertainty for the highest load task in this experiment shows the variation from 0.07 (FC5) to 0.099% (FC6). The channel AF4 (0.074%) has shown the second-lowest uncertainty in the highest cognitive load level of the experiment. Overall, the frontal region of the brain cortex shows the maximum activity with the MOT task and cognitive load.

Table 4.3 Uncertainty estimation in Level 2

Channel	Baseline value (in %)	Change in values (in %)	Subjects variation		Trials variation		Combined Uncertainty (u_c) (%)	p values
			standard uncertainty (%)	Uncertainty (u_s) (%)	standard uncertainty (%)	Uncertainty (u_t) (%)		
AF3	30.83	-7.11	0.196	0.039	0.193	0.035	0.053	0.000
F7	34.17	-9.09	0.127	0.025	0.247	0.045	0.052	0.000
F3	24.17	-9.51	0.222	0.044	0.231	0.042	0.061	0.000
FC5	31.11	-8.20	0.207	0.041	0.195	0.036	0.055	0.000
T7	33.69	-11.22	0.197	0.039	0.256	0.047	0.061	0.000
P7	28.92	-13.63	0.212	0.042	0.243	0.044	0.061	0.000
O1	28.56	-12.26	0.147	0.029	0.249	0.045	0.054	0.000
O2	32.12	-8.58	0.103	0.021	0.268	0.049	0.053	0.000
P8	24.27	-14.51	0.197	0.039	0.252	0.046	0.061	0.001
T8	38.01	-9.67	0.146	0.029	0.263	0.048	0.056	0.000
FC6	28.88	-12.75	0.237	0.047	0.237	0.043	0.064	0.001
F4	31.31	-3.13	0.201	0.040	0.228	0.042	0.058	0.006
F8	25.82	-12.63	0.169	0.034	0.268	0.049	0.059	0.000
AF4	29.69	-11.57	0.109	0.022	0.206	0.038	0.043	0.000

Table 4.4 Uncertainty estimation in Level 3

Channel	Baseline value (in %)	Change in values (in %)	Subjects variation		Trials variation		Combined Uncertainty (u_c) (%)	p values
			standard uncertainty (%)	Uncertainty (u_s) (%)	standard uncertainty (%)	Uncertainty (u_t) (%)		
AF3	30.83	-6.34	0.329	0.066	0.227	0.026	0.071	0.000
F7	34.17	-9.98	0.263	0.053	0.252	0.029	0.060	0.000
F3	24.17	-10.89	0.306	0.061	0.256	0.029	0.068	0.000
FC5	31.11	-11.39	0.231	0.046	0.178	0.020	0.050	0.008
T7	33.69	-17.58	0.237	0.047	0.297	0.034	0.058	0.000
P7	28.92	-18.26	0.258	0.052	0.288	0.033	0.061	0.000
O1	28.56	-16.97	0.249	0.050	0.305	0.035	0.061	0.000
O2	32.12	-10.72	0.233	0.047	0.324	0.037	0.059	0.000
P8	24.27	-17.43	0.340	0.068	0.303	0.035	0.076	0.008
T8	38.01	-18.04	0.193	0.039	0.313	0.036	0.053	0.000
FC6	28.88	-12.04	0.311	0.062	0.286	0.033	0.070	0.000
F4	31.31	-6.33	0.323	0.065	0.283	0.032	0.072	0.001
F8	25.82	-19.46	0.210	0.042	0.333	0.038	0.057	0.000
AF4	29.69	-12.49	0.238	0.048	0.265	0.030	0.056	0.000

Table 4.5 Uncertainty estimation in Level 4

Channel	Baseline value (in %)	Change in values (in %)	Subjects variation		Trials variation		Combined Uncertainty (u_c) (%)	p values
			standard uncertainty (%)	Uncertainty (u_s) (%)	standard uncertainty (%)	Uncertainty (u_t) (%)		
AF3	30.83	-12.20	0.334	0.067	0.273	0.050	0.083	0.000
F7	34.17	-13.27	0.277	0.055	0.332	0.061	0.082	0.000
F3	24.17	-14.42	0.378	0.076	0.318	0.058	0.095	0.010
FC5	31.11	-15.85	0.281	0.056	0.231	0.042	0.070	0.000
T7	33.69	-18.20	0.295	0.059	0.372	0.068	0.090	0.000
P7	28.92	-20.88	0.308	0.062	0.347	0.063	0.088	0.000
O1	28.56	-19.43	0.237	0.047	0.365	0.067	0.082	0.000
O2	32.12	-14.28	0.223	0.045	0.427	0.078	0.090	0.000
P8	24.27	-18.54	0.343	0.069	0.383	0.070	0.098	0.000
T8	38.01	-19.48	0.200	0.040	0.379	0.069	0.080	0.000
FC6	28.88	-16.89	0.382	0.076	0.341	0.062	0.099	0.000
F4	31.31	-8.10	0.332	0.066	0.336	0.061	0.090	0.012
F8	25.82	-20.42	0.236	0.047	0.389	0.071	0.085	0.000
AF4	29.69	-17.15	0.227	0.045	0.319	0.058	0.074	0.000

Figure 4.6 compares the combined uncertainties for the four levels (L1, L2, L3, and L4) of the cognitive load for the 14 channel locations of the brain cortex. The proportion of the uncertainty increases in each level from L1 to L4 with the increase in cognitive load. The high-cognitive load condition (L4) of the task shows the utmost changes in the uncertainty at all the channels. Furthermore, to observe the effect of the cognitive load on the overall region of the brain, the standard deviation for the values of combined uncertainties of the 14 channels is calculated. The

standard deviation for L1 is ± 0.0048 , L2 is ± 0.0054 , L3 is ± 0.0078 , and L4 is ± 0.0083 . These results show the significant different effect of the cognitive load on the brain and processes related to attention. It was observed that the variation in the data rises with the cognitive load as more disturbances happen in the dipole moments of the EEG signals.

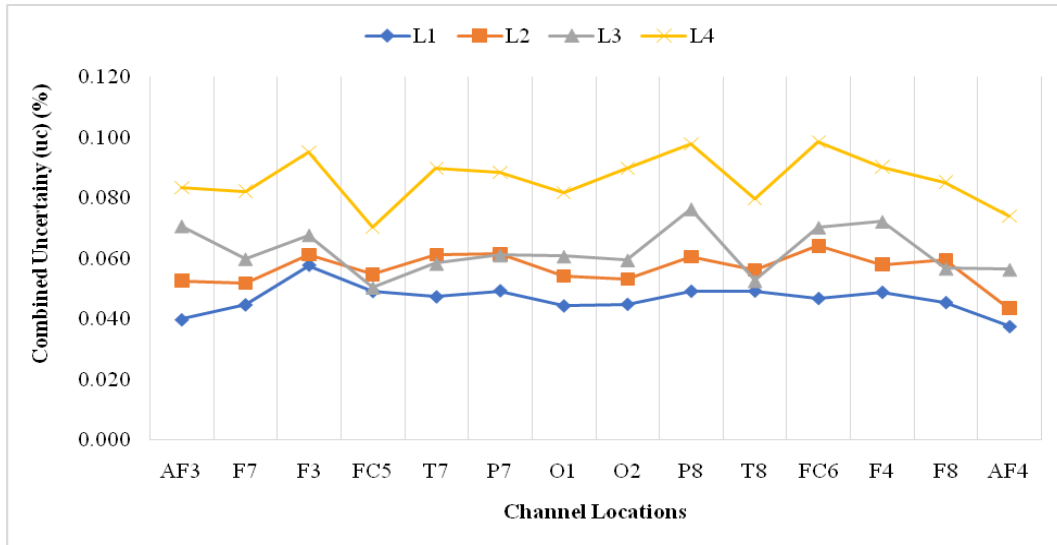


Figure 4.6 Combined uncertainty versus channels plot

The results showed the relationship between cognitive load and changes in EEG during multiple object tracking. Beta frequency band showed the variation at all scalp locations while the most variation was observed in the frontal region of the cortex. The MOT task demands high attention, and increased cognitive load used more attention resources. Previous studies stated that the beta frequency was more associated with attention in the frontal region [34,37,155]. The cognitive ability varied across the individual and strongly depends upon the type of the task [198–200]. The cognitive capacity of the individual is not constant and varies with situations and time. In this section, the variation in the EEG signals due to individual differences and repetition of trials was observed. It was found that the changes in brain signals increased with cognitive load.

4.3 Individual Differences with cognitive load

This section presents the analysis of results which are obtained from the data of all performance measures (described in Table 4.6).

4.3.1 d2 test analysis

Concentration Performance (CP) has been calculated as a measure of concentration and attention in d2 attention test as shown in Figure 4.7. CP is defined as the difference in the number of ‘hits’ (targets) and the number of distractors that were marked (errors). Ward method has been used to divide the participants into three clusters; 07 in first, 10 in second, and 08 in the third cluster. These three clusters are differentiated using CP; cluster 1 (higher performers, CP ranging from 178 to 206), cluster 2 (medium performers, CP ranging from 131 to 167), and cluster 3 (low performers, CP ranging from 93 to 125). One-way ANOVA exhibited significant effect of cluster on the task performance, $F= 70.49$, $p < 0.001$, $\eta^2 = 0.86$. Post-hoc analysis revealed a significant decrease among clusters 1 and 2 ($p < 0.00$), clusters 1 and 3 ($p = 0.00$) and also, between clusters 2 and 3 ($p = 0.017$).

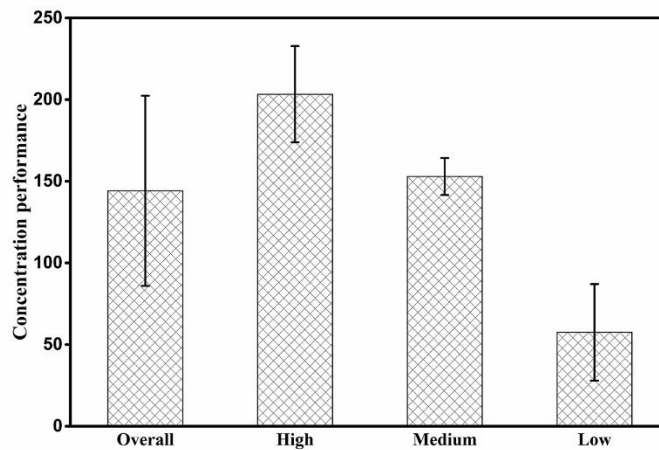


Figure 4.7 Concentration performance in d2 attention test.

4.3.2 EEG analysis

ANOVA with channel locations and levels as within the factors has been performed for theta, alpha, and beta waves. The analysis has been focused on differences in theta, alpha, and beta spectral power between three clusters and four levels.

4.3.2.1 Theta wave analysis

A repeated measure ANOVA with clusters, electrode locations and four levels as intra participant's variables showed the main effect of cluster for the theta wave ($F(2, 104) = 2.69$, $p = 0.02$, $\eta^2 = 0.04$). The higher performer cluster revealed a significant less theta band power than the medium and lower performer cluster at level 1 ($F(2, 26) = 5.37$, $p=0.011$), at level 2, $F(2,$

26) = 4.62, $p=0.019$, at level 3, $F(2, 26) = 3.67$, $p=0.029$, but not at level 4, $F(2, 26) = 0.099$, $p=0.906$. Thus, at all level, high performer cluster had low theta spectral power than other two clusters.

Taken into account level comparisons, theta spectral power for high performer's cluster increased from level 1 to level 2, $F(1, 13) = 4.48$, $p=0.024$, from level 2 to level 3, $F(1, 11) = 4.798$, $p=0.037$, but not from level 3 to level 4, $F(1, 11) = 0.42$, $p=0.17$. The same pattern has been observed when considering the medium cluster of performers for level 1 and level 2, $F(1, 19) = 4.36$, $p=0.028$, for level 2 and level 3, $F(1, 19) = 6.50$, $p=0.024$, but not for level 3 and level 4, $F(1, 19) = 0.09$, $p=0.32$. Low performers did not showed the significantly effects on theta power changes for level 1 and level 2, $F(1, 11) = 2.17$, $p=0.298$, for level 2 and level 3, $F(1, 11) = 1.95$, $p = 0.44$ and for level 3 and level 4, $F(1, 11) = 91.66$, $p=0.30$. The results showed that theta power for high and medium performers increased from two to four targets and adding a fifth target had no effect, whereas, the cluster of low performers exhibit a slighter increase from level 1 to level 4.

Table 4.6 Mean (standard deviation) of all measures across all clusters and levels.

		Level 1	Level 2	Level 3	Level 4
Theta	Overall	4.59 (0.95)	4.98 (0.95)	5.53 (0.96)	5.60 (0.92)
	High	3.76 (0.90)	4.04(0.93)	4.80(0.97)	4.91(0.79)
	Medium	4.57(0.91)	5.12(0.83)	5.77(0.84)	5.60(0.88)
	Low	5.37(1.19)	5.58(1.06)	5.83(1.15)	6.07(1.09)
Alpha	Overall	4.79(0.65)	4.68 (0.54)	4.38 (0.69)	4.07(0.78)
	High	4.70(0.61)	4.55(0.42)	4.27(0.35)	3.92(0.77)
	Medium	4.77(0.45)	4.70(0.29)	4.39(0.79)	4.06(0.54)
	Low	4.88(0.95)	4.80(1.05)	4.44(0.88)	4.18(1.13)
Beta	Overall	3.8 (0.37)	3.52 (0.45)	2.95 (0.31)	2.45 (0.33)
	High	3.54 (0.35)	2.98(0.48)	2.72(0.39)	2.35(0.29)
	Medium	3.31(0.38)	2.81(0.44)	2.44 (0.25)	2.20(0.34)
	Low	2.90 (0.37)	2.58(0.44)	2.33(0.36)	2.12(0.36)

4.3.2.2 Alpha wave analysis

A repeated measure ANOVA with clusters, electrode locations and four levels as intra participant's variables showed no significant effect of cluster for the alpha wave ($F(2, 130) = 1.158$, $p = 0.09$, $\eta^2 = 0.002$). The cluster of high performer exhibit higher alpha band power than the medium and low performer cluster, though, these changes in alpha was not significant for level 1: ($F(2, 26) = 1.023$, $p = 0.793$, level 2: ($F(2, 26) = 1.80$, $p = 0.184$, level 3: ($F(2, 26) =$

1.86, $p = 0.292$ and level 4: ($F(2, 26) = 1.437, p = 0.65$). the same of results were obtained for medium and low performers. But low performers exhibit high alpha band power than the other cluster during each level.

Taken into account level comparisons, alpha band power of higher performer's increased significantly from level 1 to level 2 ($F(1, 11) = 3.85, p=0.002$), from level 2 to level 3 ($F(1, 11) = 4.989, p=0.009$), but not from level 3 and level 4 ($F(1, 19) = 0.445, p=0.663$). Also, the medium performers showed the significant increase from level 1 to level 2 ($F(1, 19) = 3.39, p=0.027$), from level 2 to level 3 ($F(1, 19) = 4.96, p=0.011$) and for level 3 and level 4, $F(1, 19) = 0.95, p=0.08$. The significant difference was not observed for low performers between level 1 and level 2, $F(1, 11) = 0.68, p=0.18$, between level 2 and level 3, $F(1, 11) = 0.96, p=0.21$ and between level 3 and level 4, $F(1, 11) = 1.13, p=0.29$.

4.3.2.3 Beta wave analysis

A repeated measure ANOVA with clusters, electrode locations and four levels as intra participant's variables exhibit no significant effect of the cluster for beta wave ($F(2, 130) = 0.096, p = 0.909, \eta^2 = 0.002$). Analysis of beta waves for three clusters and four cognitive levels are demonstrated in Fig. 4. The cluster of high performers exhibit higher beta band power than the medium and low performers. The increase in beta power was found significant for level 1: ($F(2, 26) = 4.429, p = 0.015$), level 2: ($F(2, 26) = 5.611, p = 0.019$), level 3: ($F(2, 26) = 3.97, p = 0.011$) and level 4: ($F(2, 26) = 3.63, p = 0.001$).

Considering level comparisons, significant differences have been observed for higher performers beta band power for level 1 and level 2 ($F(1, 11) = 4.69, p=0.023$), for level 2 and level 3 ($F(1, 11) = 6.596, p=0.003$) and for level 3 and level 4 ($F(1, 11) = 5.29, p=0.000$). The medium performers followed the same pattern of analysis with significant difference for level 1 and level 2 ($F(1, 19) = 5.68, p=0.001$), for level 2 and level 3 ($F(1, 19) = 6.75, p=0.004$) and for level 3 and level 4 ($F(1, 19) = 4.164, p=0.029$). Cluster 3 (low performers) also showed significant difference between level 1 and level 2 ($F(1, 11) = 5.632, p=0.012$), between level 2 and level 3 ($F(1, 11) = 4.19, p=0.001$) and between level 3 and level 4 ($F(1, 11) = 7.32, p=0.000$).

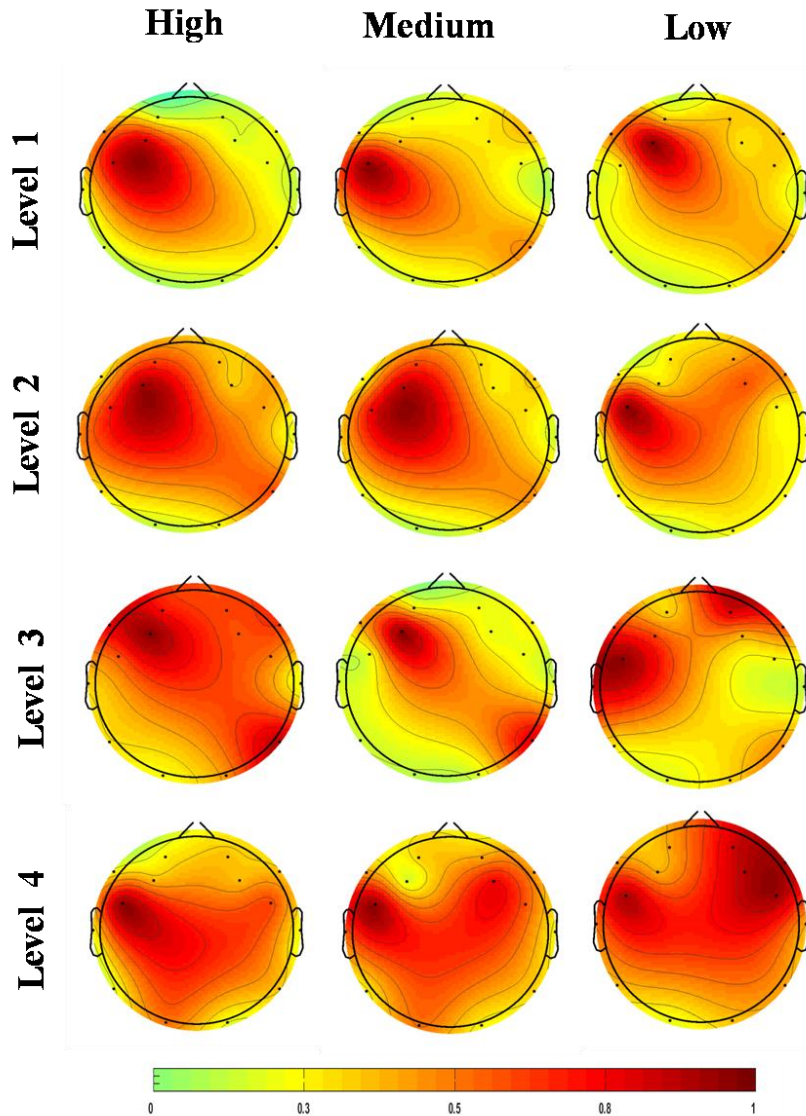


Figure 4.8 Beta band power from top to bottom of the complete scalp for levels 1 to 4 and High, medium and low performers from left to right.

The primary goal of this experiment was to explore whether individual differences in attentional capacity are related to cognitive load and physiological signals i.e. EEG frequency bands. It was observed that individual with high cognitive capacity cluster has performed better in MOT task, compared with medium and low performers. MOT effectively exerts a cognitive load on the brain and demands voluntary allocation of attention resources. Participants have to manage an increasing number of targets and the results of task performance are consistent with cognitive load theory[201]. The decline in performance with increasing cognitive load indicates that high-level cognitive functions are required in MOT. Based on the results, it is suggested that 5 targets imposed a higher cognitive load than two, three, and four targets. A cluster of high performers

was more efficient to track the targets compared to other clusters. The results reveal that it was more difficult to track more targets; therefore, participants need to apply more cognitive resources to track five targets.

It was observed that brain waves are modulated by increasing cognitive load in MOT tasks. EEG signal showed a rise in theta spectral power with the cognitive load until reaching a state of no change from four to five targets. These results are observed for the high and medium performers but low-performer participants who achieve a high value from level 1 of the experiment. The results showed the expected pattern of results which are in line with the previous findings[35] whereas some studies failed to discriminate the difficulty in different levels of the same task[202]. Earlier study has also applied cluster analysis and had failed to analyze low performer cluster due to less sample size [36], while in the current study sufficient number of participants were taken for the analysis of three clusters.

The results of alpha wave analysis showed consistency with other studies[167,203], which exhibited a decrease in alpha spectral power with increased difficulty. Three clusters exhibited no significant difference for alpha waves, but a significant increase was observed from level 1 to level 3. The changes in alpha spectral power between level 3 and levels 4 were not significant. It indicated that participants had a working memory capacity of 4 targets. Earlier studies indicated that alpha spectral power increased with the improvement of the filtering capability of relevant items and inhibition of irrelevant items[157]. In some studies, the spectral power of the alpha decreased by the task requirements and the number of elements in the working memory[35,156,204]. Both approaches demonstrated separate attention and working memory mechanisms. In this experiment, the desynchronization of alpha waves was due to a decrement in the filtering capability of irrelevant information. Similarly, beta spectral power also showed the desynchronization with the cognitive workload. Earlier study supports the current findings and found a decrease in beta spectral power with cognitive workload [205]. While one study on brain wave analysis with cognitive workload found desynchronization in beta with the cognitive workload. Beta power as investigated by[187] with an increase in outward focus and learning the task. Lastly, the results showed an increase in theta and decrease in alpha, beta power with cognitive load. And, individuals have different cognitive capacity.

4.4 Cognitive Training and Pre-post-post2 Analysis

The psychological and physiological analysis of the results to analyze the effects of cognitive training is discussed.

4.4.1 Psychological Tests Outcomes

In this section, descriptive sets of psychological tests are presented. Statistical analysis of the cognitive functions based on the psychological test was performed using IBM SPSS Statistics 23 software. The psychological tests included Corsi, Dspan, Stroop, CPT, TWOB, and IDN tests to measure cognitive functions. Two statistical tests were used to find the effect of the training (between pre and post-measurement) and groups. T-test employed to investigate the difference between players and non-players and ANOVA found the statistical difference between three groups (active, passive, and control group) and two test times (pre and post). Similarly, the test was performed to analyze the longevity effect of the cognitive training.

4.4.1.1 Working memory measures

a) Corsi test

Statistical analysis was performed on the two measures of the Corsi test, *i.e.*, total score, and memory span. To investigate the effects of sports expertise on working memory capacity, a t-test was applied between the football players (all player participants, active and passive groups) and non-player participants (control group). The total score and memory span of players was found significantly ($p < 0.05$) higher by 13.84% (Figure 4.6) and 11.75%, respectively (Figure 4.7). Further, the analysis was carried out on the active, passive, and control groups. A mixed analysis of variance (ANOVA) with two factors, *i.e.*, test time (pre-test, post-test) and three groups, was completed to investigate the effects of cognitive training on working memory.

A significant ($p < 0.05$) enhancement of 12.81% total score (Figure 4.9) and 16.66% memory span (Figure 4.10) was observed between pre and post-measurement for the active group. Whereas no significant ($p < 0.05$) changes were observed for other groups. A t-test was applied between the post-measurement of the active-passive group and the active-control group. The memory span of the active group was found significant ($p < 0.05$) higher by 10.29% and 31.51% compared to the passive and control group, respectively. Whereas, for the total score, it was found 10.87% and 28.30%. These results indicate that the cognitive training program efficiently

enhanced the working memory capacity of the sports persons. A mixed between within-subject ANOVA with the factors test time (post-post2) and groups (active-passive-control) was computed to investigate the effect of the retention time interval on the cognitive performance of the groups. A significant ($p < 0.05$) decrease in the working memory of the active group in retention time is found for both measures, *i.e.*, the total score (Figure 4.11) and memory span (Figure 4.12). These results indicate that the effect of cognitive training is time-limited, and it decreases with time.

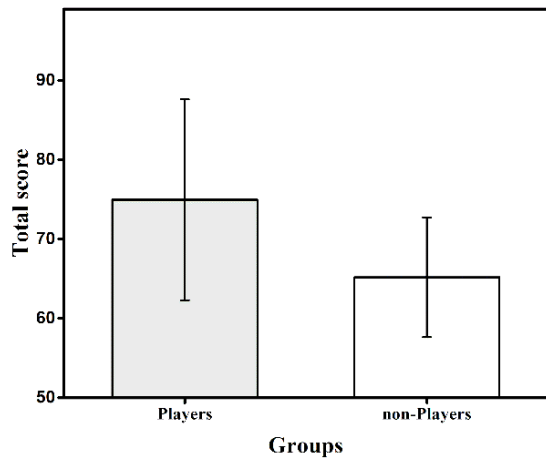


Figure 4.9 Average total score in Corsi for players and non-players

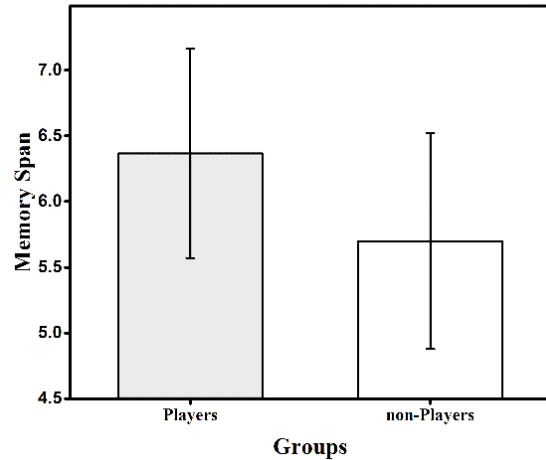


Figure 4.10 Average memory span in Corsi for players and non-players

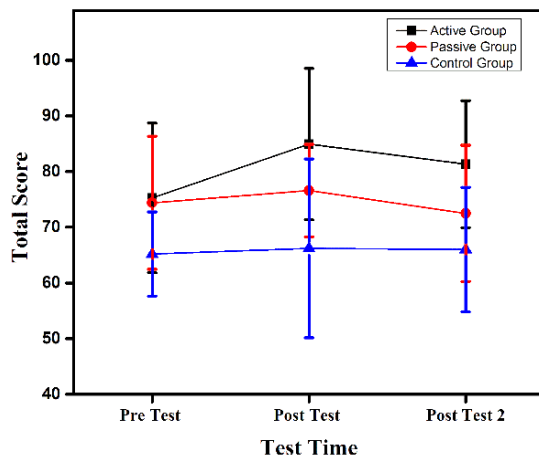


Figure 4.11 Average total score in Corsi during three test time for three groups

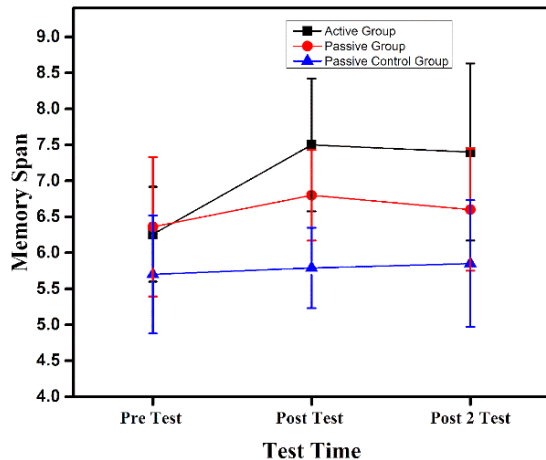


Figure 4.12 Average memory span in Corsi during three test time for three groups

b) *Dspan Test*

A significant ($p < 0.05$) difference of 13.50% in response time was observed between players and non-players (Figure 4.13). Players had taken less time to complete the task as compared to non-players. Further, a comparison between the pre and post-measure values of Dspan test showed a significant decline in response time of the active group. There were insignificant ($p > 0.05$) changes found in the active-passive and active-control groups. The response time of the active group increased significantly by 9.75% concerning retention time (Figure 4.14).

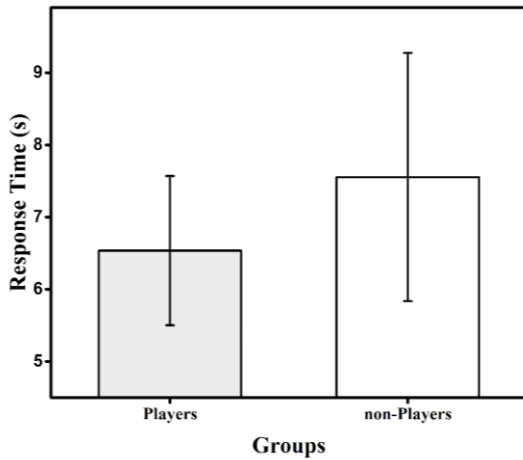


Figure 4.13 Average response time in Dspan for players and non-players

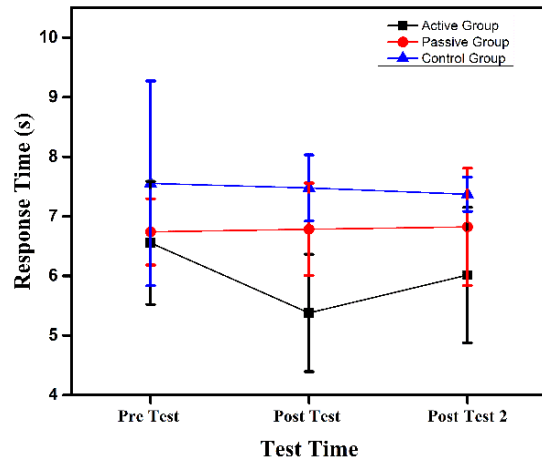


Figure 4.14 Average response time in Dspan during three test time for three groups

c) *TWOB Test*

The t-test revealed a significant ($p < 0.05$) decrease of 7.5% in the accuracy of non-players as compared to players (Figure 4.15). Next, the analysis between the pre and post-measurement of active, passive, and control groups report the significant effect ($p < 0.05$) for the cognitive training using mixed ANOVA (Figure 4.16). The post-hoc test revealed a significant 9.42% improvement in the accuracy of the active group. Whereas, for passive and control groups, it was found insignificant. A significant ($p < 0.05$) difference was found between post measurements of active-passive and active-control groups by 6.18% and 17.25%, respectively. The comparison between the measures of the post and post2 test showed a significant ($p < 0.05$) decline in the working memory capacity of the action with respect to time.

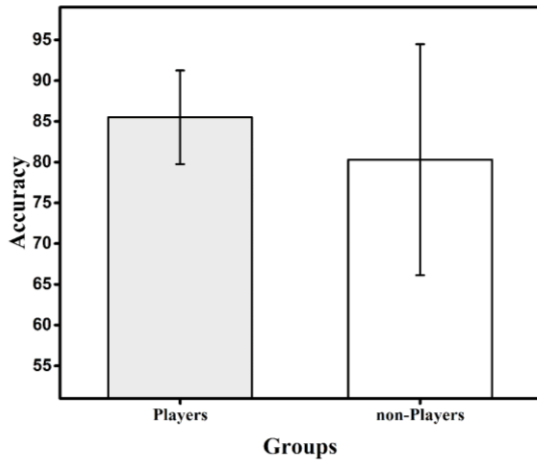


Figure 4.15 Average accuracy in TWOB for players and non-players

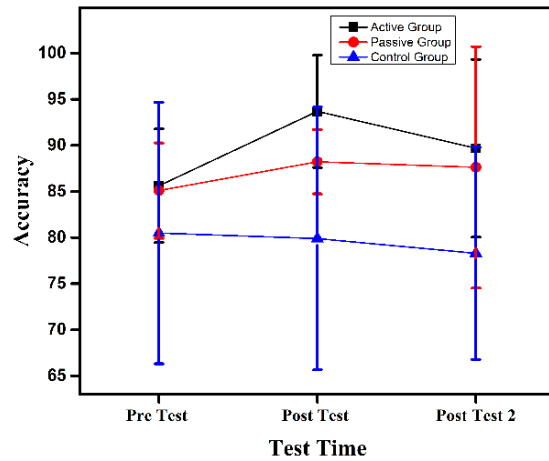


Figure 4.16 Average accuracy in TWOB during three test time for three groups

4.4.1.2 Attention measures

a) CPT Test

The t-test was applied between players and non-players to examine the effects of the sports exercise on attentional capacity. The differences between players and non-players were found insignificant (Figure 4.17). Further, analysis between the pre and post-measurement of active, passive, and control groups was performed. A mixed ANOVA with two factors, *i.e.*, test time and three groups exhibited significant ($p < 0.05$) interaction. Post-hoc analysis revealed a significant ($p < 0.05$) decrease by 9.41% response time of the active group. Whereas insignificant ($p > 0.05$) changes were observed between the pre-post measurement of the passive group and control group (Figure 4.18). The t-test depicted significant differences ($p < 0.05$) between the post measurements of the active-passive group and the active-control group.

b) Stroop Test

The analysis revealed that the response time of players was significantly ($p < 0.05$) less by 5.51% as compared to non-players (Figure 4.19). Further, analysis between the pre and post measurement of active, passive, and control groups report the significant ($p < 0.05$) effect of cognitive training. Differences between response time revealed significant ($p < 0.05$) interaction between test time and groups. Post-hoc analysis showed a significant ($p < 0.05$) decrease by 10.88% response time of the active group. No significant ($p > 0.05$) changes were observed between the pre-post measurement of other groups. The difference between post measurements

of active-passive (10.64%) and active-control (27.34%) groups were found significant ($p < 0.05$). The response time of the active group increased in post2 measurement (Figure 4.20).

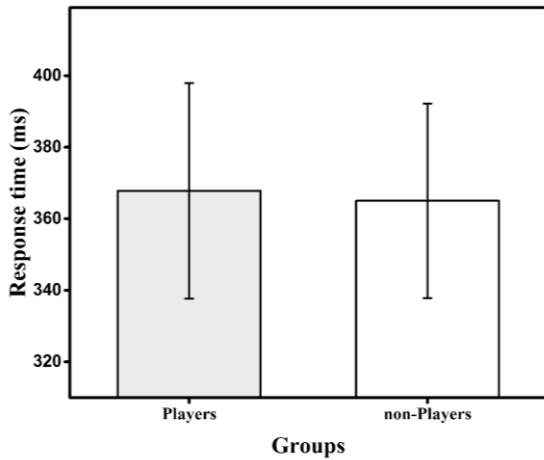


Figure 4.17 Average response time in CPT for players and non-players

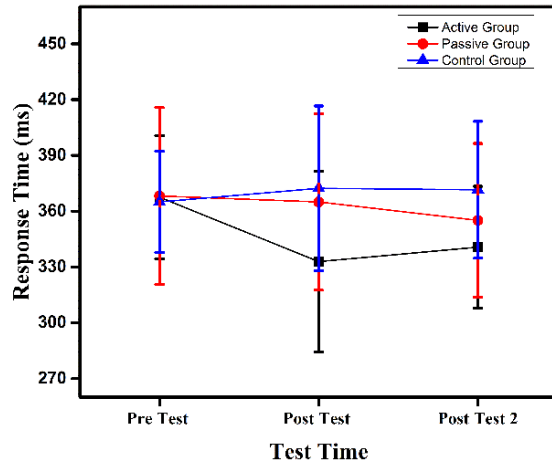


Figure 4.18 Average response time in CPT during three test time for three groups

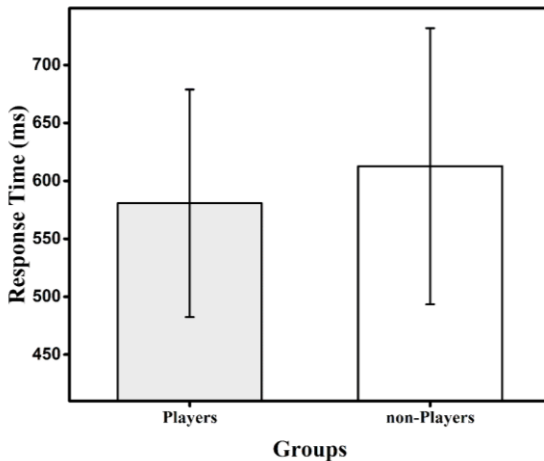


Figure 4.19 Average response time in stroop for players and non-players

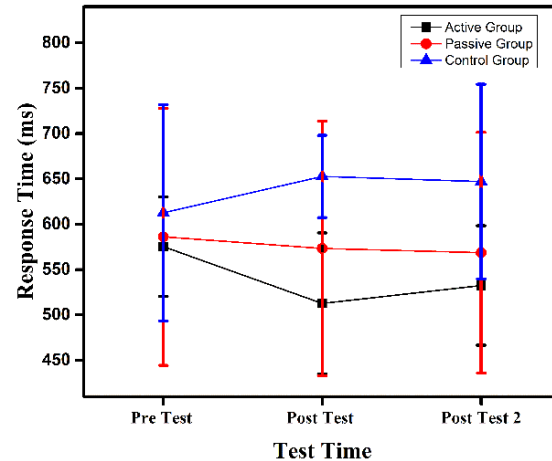


Figure 4.20 Average response time in stroop during three test time for three groups

c) *IDN Test*

A significant high in the accuracy of players compared to non-players was found as 9.09% (Figure 4.21). The effect of the cognitive training interval was assessed using mixed ANOVA, which found significant ($p < 0.05$) changes in the accuracies between the pre and post-measurement (Figure 4.22). The accuracy of the active group was improved by 7.36%.

Significant ($p < 0.05$) differences were observed between post measurements of active-passive (11.52%) and active-control groups (12.99%). The effect of retention time was observed using mixed ANOVA and found significant ($p < 0.05$) with the factors test time (post-post2) and groups. A significant decrease of 6.78% was observed in the active group. Tables 4.7-4.9 summarized the results of the psychological tests for active, passive, and control groups for three test times.

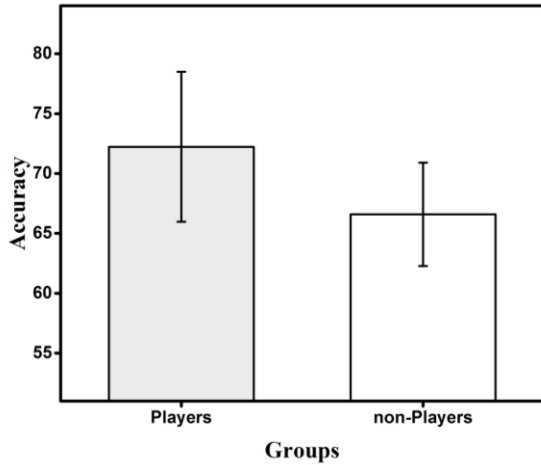


Figure 4.21 Average accuracy in IDN for players and non-players

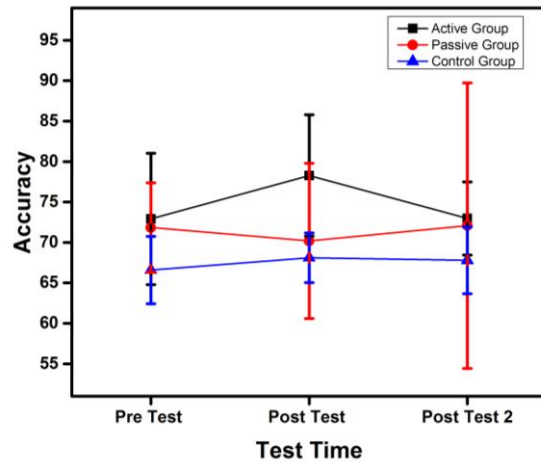


Figure 4.22 Average accuracy in IDN during three test time for three groups

Table 4.7 Average and standard deviation (SD) for performance variables of active group

Psychological Tests	Active group					
	Pre		Post		Post2	
	Mean	SD	Mean	SD	Mean	SD
Corsi (Memory Span)	6.259	0.659	7.500	0.923	7.400	1.230
Corsi (Total Score)	75.290	13.430	84.940	13.600	81.350	11.400
Dspan (Response Time (s))	6.5537	1.0333	5.3784	0.9856	6.0139	1.1369
Stroop (Response Time (ms))	575.300	54.700	512.700	77.700	532.500	65.900
CPT (Response Time (ms))	367.500	33.100	332.900	48.500	340.700	32.700
TWOB (Accuracy)	85.620	6.160	93.690	6.090	89.690	9.630
IDN(Accuracy)	72.910	8.130	78.280	7.500	72.970	4.510

Table 4.8 Average and standard deviation (SD) for performance variables of passive group

Psychological Tests	Passive group					
	Pre		Post		Post2	
	Mean	SD	Mean	SD	Mean	SD
Corsi (Memory Span)	6.362	0.966	6.800	0.630	6.600	0.850
Corsi (Total Score)	74.400	11.950	76.600	8.310	72.500	12.250
Dspan (Response Time (s))	6.7391	0.5561	6.7824	0.7763	6.8232	0.9856
Stroop (Response Time (ms))	586.100	141.800	573.300	140.300	568.600	132.800
CPT (Response Time (ms))	368.200	47.500	365.000	47.500	355.100	41.300
TWOB (Accuracy)	85.100	5.170	88.230	3.480	87.620	13.090
IDN(Accuracy)	71.840	5.520	70.190	9.610	72.080	17.640

Table 4.9 Average and standard deviation (SD) for performance variables of control group

Psychological Tests	Control group					
	Pre		Post		Post2	
	Mean	SD	Mean	SD	Mean	SD
Corsi (Memory Span)	5.700	0.823	5.790	0.559	5.850	0.880
Corsi (Total Score)	65.200	7.550	66.200	16.060	66.000	11.190
Dspan (Response Time (s))	7.5536	1.7197	7.4764	0.5557	7.3703	0.2885
Stroop (Response Time (ms))	612.700	119.200	652.700	45.300	647.100	107.300
CPT (Response Time (ms))	365.000	27.200	372.300	44.300	371.500	36.800
TWOB (Accuracy)	80.500	14.180	79.900	14.250	78.300	11.510
IDN(Accuracy)	66.590	4.170	68.110	3.080	67.790	4.130

4.4.2 EEG Analysis

The EEG data were recorded and processed separately for pre, post, and post2 sessions and subsequently distributed into groups of players (active and passive) and control groups. Three frequency bands, theta, alpha, and beta were extracted from the recorded EEG data. The frontal region of the brain is related to working memory and attention. The average of the frontal region (AF3, F3, F7, FC5, FC6, F8, F4, and AF4) has opted for analysis. The coupling strength through brain connectivity measure (PDC) was calculated throughout the scalp.

4.4.2.1 Theta band analysis

The PSD of the theta band demonstrates high values for the non-players compared to players (Table 4.10). The t-test revealed significant ($p < 0.05$) high in PSD of all levels of MOT. The comparative analysis of pre and post-theta PSD reported a significant effect of cognitive training

(Table 4.11). A mixed ANOVA with two factors, *i.e.*, tests time (pre-test, post-test) and three groups, showed significant ($p < 0.05$) interaction. Post-hoc analysis revealed that the theta of the active group significantly ($p < 0.05$) decreased by 39.40% while insignificant changes were observed in other groups. The comparison of post-measurement of active-passive (40.57%) and active-control (26.80%) groups showed the significant effect of cognitive training. A mixed between within-subject ANOVA with the factors test time (post-post2) and groups was computed to investigate the effect of the retention time interval. There was a significant increase of 24.95% observed in theta PSD of the active group.

Table 4.10 Average and standard deviation (SD) for theta PSD of players and non-players

MOT levels	Players		Non-players	
	Mean	SD	Mean	SD
L0	1951.50	748.12	3435.70	757.64
L1	2138.24	240.78	3555.14	1132.62
L2	2508.26	2277.96	4380.64	1373.94
L3	2330.02	1598.12	4988.54	555.70
L4	2066.12	233.80	8903.00	603.38
L5	2230.44	2020.74	4028.64	1474.00
L6	1958.50	355.58	3534.00	206.04
L7	2521.76	754.48	5818.44	804.50
L8	1885.52	390.28	9233.30	710.46
L9	1957.00	1857.98	4240.42	380.34
L10	2214.52	1547.74	4562.80	1498.24
L11	2169.02	1223.14	3966.06	342.42
L12	2250.48	602.12	5019.60	230.76
L13	2214.38	598.00	6738.18	570.76
L14	2135.62	1419.48	7231.34	260.22

Table 4.11 Average and standard deviation (SD) for theta PSD of three groups

Groups	Pre		Post		Post2	
	Mean	SD	Mean	SD	Mean	SD
Active group	5309.05	726.73	3216.93	444.19	4019.55	541.58
Passive group	5625.12	880.41	5413.02	612.89	5569.23	589.64
Control group	2168.76	857.89	2354.51	655.01	2462.89	412.22

4.4.2.2 Alpha band analysis

The PSD of the alpha band demonstrates high values for the players compared to non-players (Table 4.12). The t-test revealed significant ($p < 0.05$) high in PSD of all levels of MOT. The comparative analysis of pre and post alpha PSD reported a significant effect of cognitive training (Table 4.13). A mixed ANOVA with two factors, *i.e.*, test time (pre-test, post-test) and three groups, revealed a significant effect of cognitive training. Further, post-hoc analysis showed that the alpha of the active group significantly increased by 30.73% while insignificant changes were observed in other groups. A significant reduction of 21.46% in active-passive and 45.33% active-control groups was assessed. A mixed between within-subject ANOVA with the factors test time (post-post2) and groups were examined to investigate the effect of the retention time. There was a significant decrease in alpha PSD by 14.86% of the active group.

Table 4.12 Average and standard deviation (SD) for alpha PSD of players and non-players

MOT levels	Players		Non-players	
	Mean	SD	Mean	SD
L0	6929.92	1672.88	4854.20	324.08
L1	6323.08	493.36	4740.72	495.76
L2	6074.04	3008.52	4600.04	2364.68
L3	5705.72	1757.52	4392.56	2718.88
L4	5568.04	123.72	3932.64	1474.64
L5	5846.08	1058.56	4398.32	3199.56
L6	5587.60	753.52	4253.20	206.44
L7	5470.36	1680.40	3900.92	2393.08
L8	5457.44	1472.64	3892.72	2045.76
L9	5357.88	482.64	3611.08	2753.52
L10	5387.48	3087.28	3684.36	2754.68
L11	4659.12	715.48	2777.08	1309.04
L12	5122.88	950.88	3548.60	2458.80
L13	4308.52	1426.36	2284.28	2684.12
L14	4267.00	366.80	1900.00	3227.00

Table 4.13 Average and standard deviation (SD) for alpha PSD of three groups

Groups	Pre		Post		Post2	
	Mean	SD	Mean	SD	Mean	SD
Active group	5471.01	1270.04	7152.24	1112.32	6089.12	1075.22
Passive group	5621.77	1070.30	5888.11	1009.03	5987.42	842.47
Control group	3784.71	2027.34	3895.17	1902.43	3968.74	972.94

4.4.2.3 Beta band analysis

The PSD of the beta band demonstrates high values for the players compared to non-players (Table 4.14). The t-test revealed significant ($p < 0.05$) high in PSD of all levels of MOT.

Table 4.14 Average and standard deviation (SD) for beta PSD of players and non-players

MOT levels	Players		Non-players	
	Mean	SD	Mean	SD
L0	7386.76	1628.93	4195.73	1608.46
L1	7643.55	2435.13	4597.22	517.68
L2	7418.38	2953.97	5392.76	4897.61
L3	8725.36	1194.76	5009.54	3435.96
L4	8141.45	1297.27	4442.16	502.67
L5	8661.58	3169.10	4795.45	4344.59
L6	7598.10	442.99	4210.78	764.50
L7	7509.65	1729.68	5421.78	1622.13
L8	6851.60	1527.49	4053.87	839.10
L9	7116.90	817.73	4207.55	3994.66
L10	8810.02	3221.22	4761.22	3327.64
L11	7527.03	736.20	4663.39	2629.75
L12	8792.14	496.13	4838.53	1294.56
L13	8487.09	1227.13	4760.92	1285.70
L14	8547.38	559.47	4591.58	3051.88

The comparative analysis of pre and post-beta PSD reported a significant effect of cognitive training (Table 4.15). It was revealed that the beta of the active group significantly ($p < 0.05$) increased by 21.69% while insignificant changes were observed in other groups. The comparison of post measurements showed that the active group had a significant ($p < 0.05$) high beta by 20.77% compared to passive and 52.22% compared to control groups. A mixed between within-

subject ANOVA with the factors test time (post-post2) and groups was computed to investigate the effect of the retention time interval. PSD of beta-band significantly decreases by 11.82% of the active group.

Table 4.15 Average and standard deviation (SD) for beta PSD of three groups

Groups	Pre		Post		Post2	
	Mean	SD	Mean	SD	Mean	SD
Active group	8414.46	1562.48	10239.60	1846.22	9028.44	1639.21
Passive group	8219.32	1248.65	8478.10	1422.48	8675.19	1099.32
Control group	4662.83	2274.46	4892.36	1672.24	4846.62	1329.48

4.4.2.4 PDC analysis

The magnitude of coupling strength varies between zero and one for a pair of electrodes. The total coupling strength was calculated which was the sum of the coupling strength between all pairs of the electrodes. The coupling strength of connectivity flow, PDC, was calculated for the alpha frequency band of all participants. The PDC for players was found 47.5% higher as compared to non-players (Figure 4.23). The comparative analysis of pre and post PDC was done to assess the effect of cognitive training and found 55% in the active group (Figure 4.24).

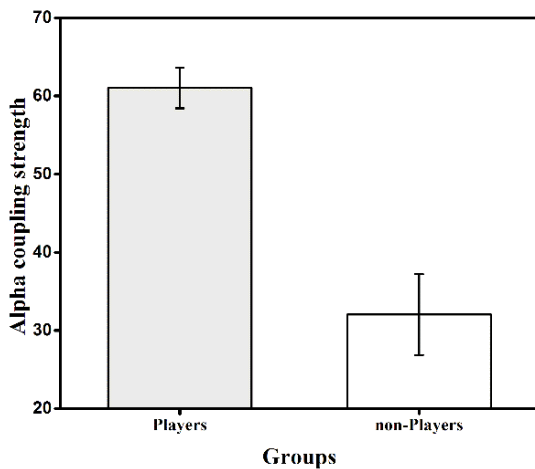


Figure 4.23 Average alpha coupling strength for players and non-players

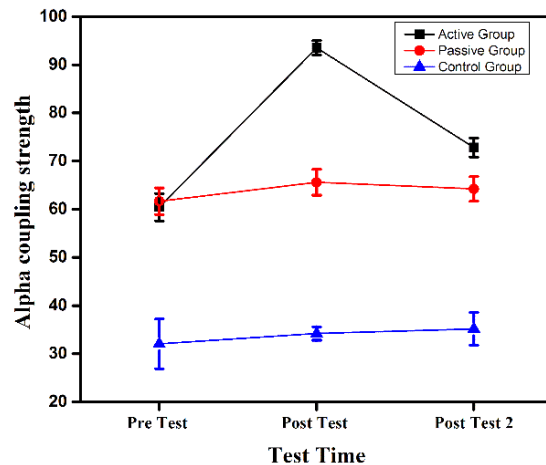


Figure 4.24 Average alpha coupling strength during three test time for three groups

The coupling strength of the active group was exhibited 1.5 times higher than the passive group and three-time higher compared to the control group in post measurement. Coupling strength was observed decline with 22.58% in post2 measurement. Figure 4.25 shows the flow of connectivity

throughout the scalp for the player and non-player. Figure 4.26 shows the flow of connectivity throughout the scalp for three groups at three-time intervals.

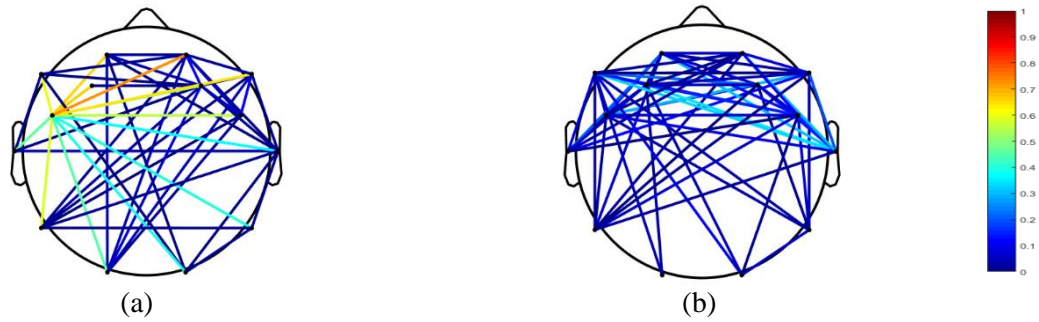


Figure 4.25 Connectivity flow among EEG channels (a) players (b) non-players

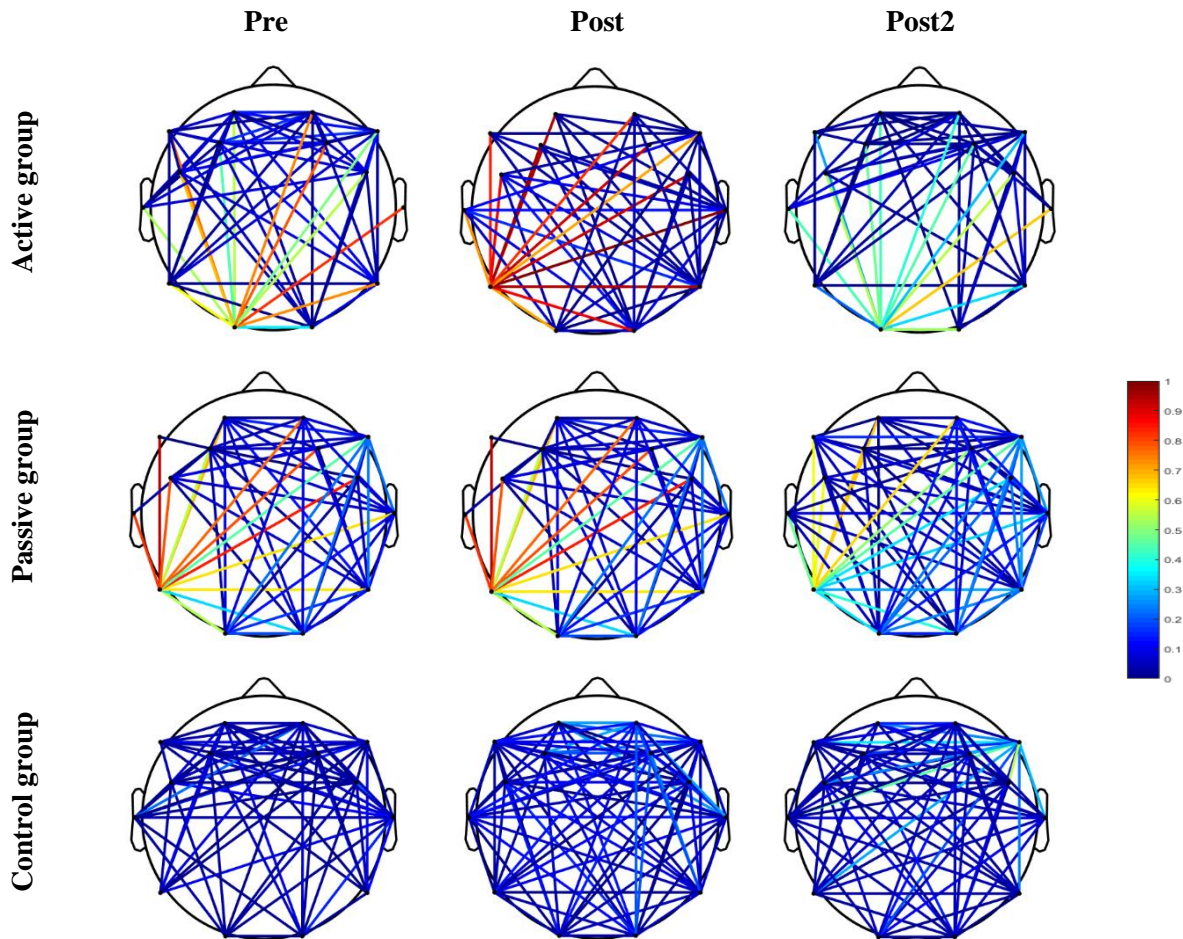


Figure 4.26 Connectivity flow among EEG channels

The performance of the players was found better than the non-players in the psychological measurement. It suggested that expertise in sport helped in the other cognitive domain. The results were consistent with previous studies regarding the cognitive ability of sports players. In football, players continuously focus on the positions of the teammates and opponents with the variation in direction [9,31,45]. This ability made the player better than the non-players. According to the literature, the high theta is related to the cognitive load, and increased pressure situations demand high cognitive ability [35,36,206]. Earlier research found the relationship between cognitive tasks and EEG frequency bands [145]. Less theta power of players suggested that they were comfortable in the high attention-demanding task. The synchronization in alpha and beta bands is associated with attention, working memory, and relaxation [34,35,111,158]. Here, the findings revealed that players had high alpha and beta power. The comparative analysis of EEG frequency bands showed higher activation in the brain of the players. These results were supported by the measurement of the flow connectivity. The high alpha coupling strength represented less cognitive load and decreased cognitive load [153,207,208]. Here, it was observed players' coupling strength was more compared to the non-players.

In the present research work, the effects of cognitive training on cognitive skills were evaluated. The results showed that training efficiently improved the cognitive capacity of the players. Significant differences were observed in the pre and post-measurement. The active group significantly performed better in the psychological tests compared to the pre-measurement. The brain waves were significantly modulated by cognitive training. A desynchronization in theta, synchronization in alpha, and beta were observed. The comparison of the three groups in post-measurement showed that the passive group had better cognitive capacity than the control group, but not better than the active group. Previous studies reported that cognitive training improved cognitive skills and results in better performance [13,31,209].

In this work, three factors were incorporated in the training model, *i.e.*, background noise, the field of view, and variation in objects. We found that brain activities were modulated by cognitive training and an increase in beta activity was observed in the active group. Earlier research showed that background noise reduced the beta frequency and caused a lack of attention [28]. Hence, an increase in beta showed that the active group improved attention and reduced the effect of background noise. The results of flow connectivity support these findings and indicated that the cognitive training helped the players to maintain a high attention level in presence of

background noise. The increase in targets and distractors demanded high working memory and increased the cognitive load. Players needed to successfully filter the target and distractors. In a previous study, the effect of cognitive training was observed using contralateral delay activity (CDA). It is another measure of working memory[209]. They found an increase in CDA and observed enhancement in working memory. Their results concluded that players with high working memory capacity were able to track more targets. It was also evident that high working memory increased the attention distribution capacity[210]. In the current study, we observed the increase in alpha and beta activity which indicated the increase in working memory. The results of the present study concluded that cognitive training increased the capacity of tracking the targets and successfully filtered out the distractors. In soccer, players need to divide their attention in multiple chunks and demands high working memory. In present study, the screen in level 7 and 9 was divided into four parts and subjects needed to divide their attention in four locations at the same time. The increase in alpha and beta activities was observed in these two levels. The increase in alpha and beta activities was associated with the enhancement in attention and working memory. Thus, the findings of the present study concluded that the cognitive training enhanced the cognitive functions and effectively helped the players to reduce the influence of background noise, field of view, and variation in objects on cognitive performance.

The comparative analysis of the post and post2 measurement showed that cognitive skills decreased after three months. The performance of the players was declined in psychological tests as well as physiological measurement. These results conclude that the effect of the cognitive training was time-limited. The player demands high cognitive abilities and should be maintained for a long time [5,71,211]. These results of the present thesis work showed that cognitive training significantly improved brain health, but it was declined with time. It suggested that the players should continuously participate in cognitive training.

This chapter presents the results of the experimentation. The comparative analysis of 109 types of wavelets was performed, and bior3.1 wavelet was found to be better in denoising and decomposition of EEG signals. It was observed that performance decline with cognitive load. The variation in brain signal increased with cognitive load, and the frontal region of the cortex was evaluated as the most activated area in a cognitive task. Differences in individual brain waves were observed with cognitive load. Then, sport expertise was reflected in the psycho-physiological measurement. The psycho-physiological assessment found significant improvement in cognitive skills after cognitive training. The effect of cognitive training was time-limited and decay with time.

Chapter 5

Validation of Cognitive Training Effects

The advancement in technology has made it possible to perform open-ended estimations of the human cognitive state using cognitive tasks. In particular, the mental workload is related to working memory and attention and intricate in a variety of sports applications. It is necessary to derive cognitive tasks to estimate attention level based on multiple stimulus. The cognitive task should be able to induce a user's baseline and high attention level. Also, the cognitive task used in training sessions would be more effective if it is intuitive to typical users and time-efficient. These requirements should be met even in realistic use-case scenarios.

In the earlier chapter, cognitive task-based attention estimation has been used, which allows us to measure the effect of the cognitive training. Six cognitive measure tests were used to assess the cognitive capacity of the subjects; Corsi, Dspan, Stroop, IDN, TWOB, and CPT tests. In these cognitive tests, visual stimuli were used to estimate the cognitive capacity of the subjects. It was observed that the interference noise is a very important factor, which affects the cognitive performance of the players[29]. So, the performance of the players should be evaluated with the cognitive task which used audio as well as visual stimuli. Secondly, players need to focus on multiple areas while tracking the target in the field[136]. The cognitive task should also be efficient to measure this capacity of the subjects. Next, the cognitive measure tasks which were used in the previous chapter; can be utilized with the specific software; PEBL and Cogstatebattery. It was desired to develop cognitive tasks which do not require any specific software[25,56,212].

Thus, for practical issues regarding cognitive measure tasks to assess the cognitive capacity with the audio-visual stimuli and visual search capacity, four cognitive tasks were redesigned in open source available software (MATLAB) which is exposed to different types of stimuli. The performance accuracy in each task was measured before (pre) training and post-training sessions. Initially, the pre-training measurement was performed to evaluate the cognitive capacity of the subjects. Then the cognitive training was given to the subjects. After that, post-measurement was performed to evaluate the effect of the cognitive training.

5.1 Design of Cognitive Tests

The four tasks were the one-beep attention test; two-beep attention test, left-right visual attention test, and visual search attention test were considered. The tasks are designed in MATLAB.

5.1.1 One-Beep Attention Test

The task was designed to measure the attention capability of the subjects to audio stimuli. Before starting the task, the subject is asked to fill in the details; Name, Gender, and Age. The run time of the task is 10 minutes. In this task, the subject hears a beep of 0.1 second duration and then a message box "Press Enter" is appeared on the screen for 0.5 second. The subject has to press 'Enter' key within 0.5 second. After 0.5 second, message will disappeared. One score is counted if the subject responds to the stimuli in 0.5 second. The score is counted zero in the situation of no response or delay in response after 0.5 second. The minimum and maximum time delay between two consecutive beeps are 01 and 03 seconds, respectively. When the task will finish, a message box 'Task completed' appears on the screen. Accuracy is calculated at the end of the task. Subjects perform two-minute practice trials to become familiar with the task and its results do not include in the score. Figure 5.1 shows the screen shots of the messages displayed in the task.

5.1.2 Two- Beep Attention Test

The task is designed to measure the divided attention of the subjects between two audio stimuli. Before starting the task, the subject is asked to fill in the details; Name, Gender, and Age. The run time of the task is 10 minutes. In this task, the subject is asked to respond to beep stimuli of two types (beep-01 and beep-02). The time duration of each beep is 0.1 second. When beep-01 is heard, the subject has to press 'n' and for beep-02, press 'm' within 0.5 second. The minimum and maximum time delay between two stimuli are 01 and 03 seconds, respectively. One score is counted if the subject response correctly to stimuli in 0.5 second. The score is counted zero for no response, incorrect response, and delayed response after 0.5 second. Thereafter, when the task will finish, the 'Task completed' message appears on the screen. Accuracy is calculated at the end of the task. Subjects perform two-minute practice trials to become familiar with the task and its results do not include in the score. Figure 5.1 (a, b, c, and e) shows the screen shots of the messages displayed in the task.

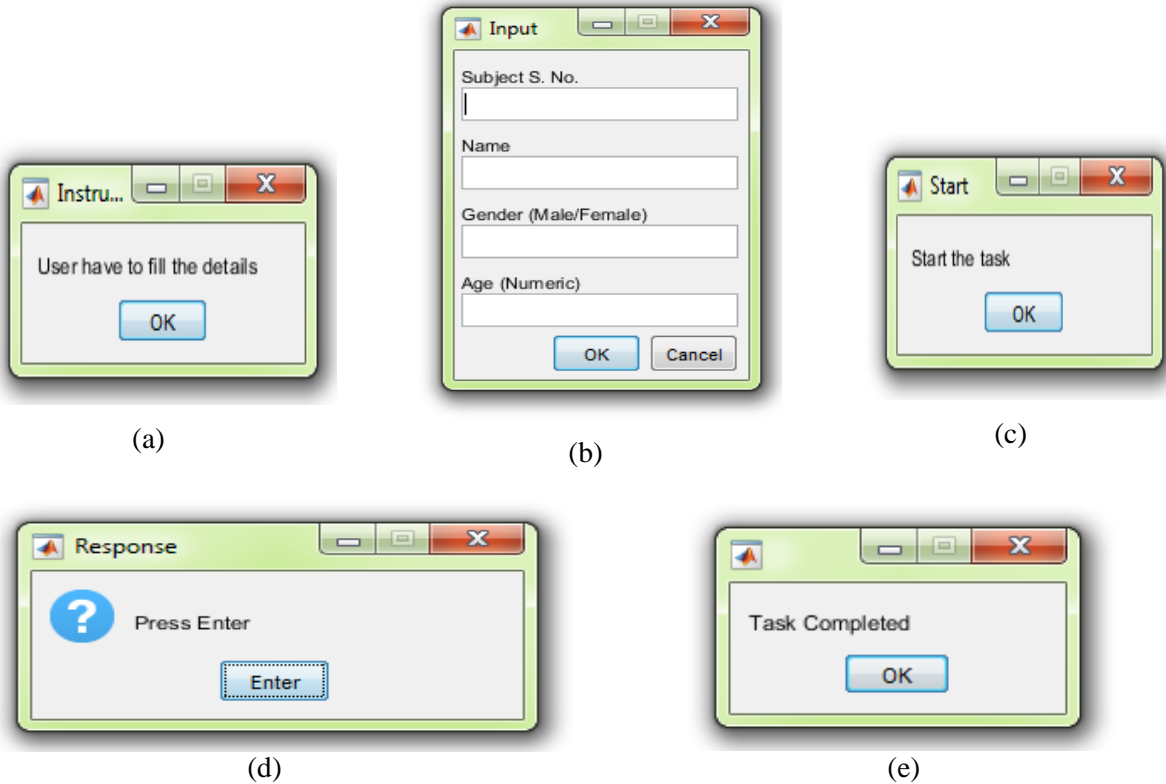


Figure 5.1 Screen shots of the tasks. (a) Initial instruction to fill the details (b)user detail menu (c) message to start the task(d)message display to response the stimuli (e) message at the end of task

5.1.3 Left-Right Attention Test

The task is used to measure the divided attention of the subjects using visual stimuli. Before the starting of a task, the subject has to fill in the details; Name, Gender, and Age. The run time of the task is 10 minutes. In this task, an image with two squares and one arrow in the middle of these squares will be displayed on the screen for 0.5 second. Both the squares are empty. Subjects have to focus on the box which is indicated by the direction of the arrow (see Figure 5.2 (a) and (d)). After that, an image will be displayed which have an impression ('+' or 'X') inside of the box directed towards the arrow. If the arrow is directed towards the left, then the next image with an impression on the left box will be displayed (see Figure 5.2 (b), (c), (e), and (f)). If the arrow is directed towards the right, then the next image will have an impression in the right box. There is a total of four types of images. The minimum and maximum time delay between two stimuli are 02 and 04 seconds, respectively. For the '+' in the image, the subject has to press 'm' while for the 'x', press 'n'. Subjects have to respond within 0.5 second. Score one is counted for correct response otherwise zero scores are given. When the task will finish, the

‘Taskcompleted’ message appears on the screen. Accuracy is calculated at the end of the task. Subjects perform two-minute practice trials to become familiar with the task and its results do not include in the score. Figure 5.1 shows the screen shots of the messages displayed in the task. Figure 5.2 shows the images used for the stimuli in the task.

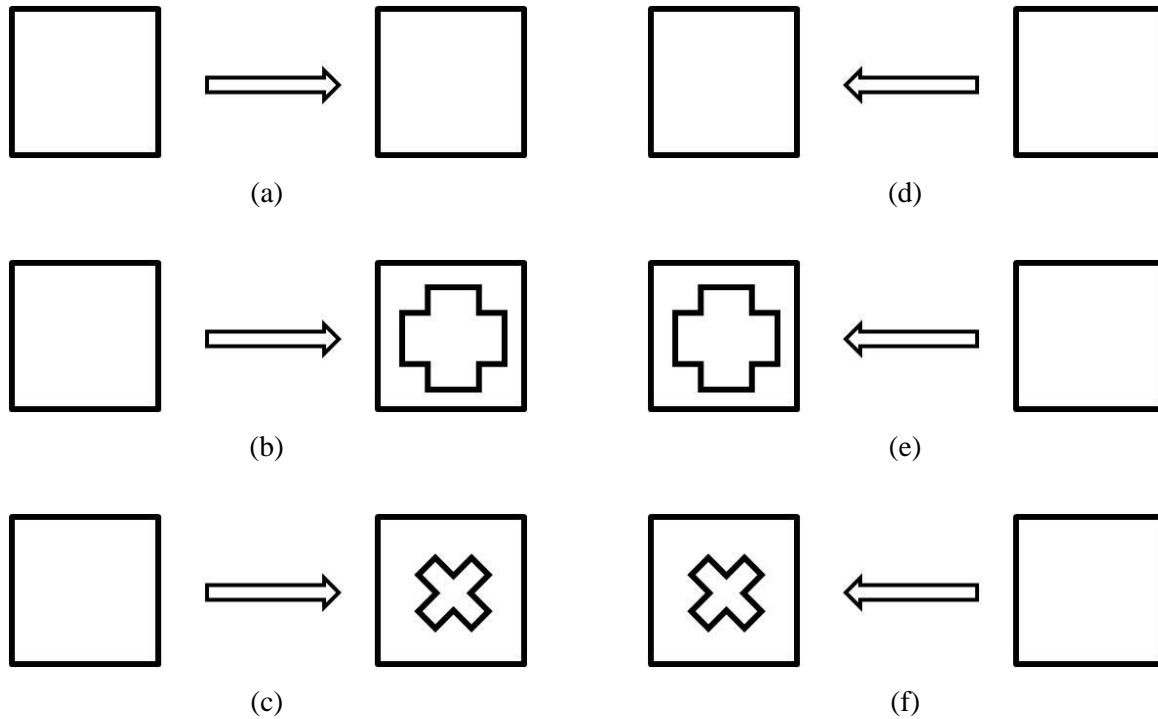


Figure 5.2 Images display in the task

5.1.4 Visual Search Attention Test

The task is created to measure the attention of the subjects using visual stimuli. Before the starting of the task, the subject has to fill in the details; Name, Gender, and Age. The run time of the task is 10 minutes. In this task, an image of rectangular shape is displayed on the screen which has a 4*7 matrix of digital ‘5’ or ‘2’. In the stimulus images, there is the possibility of one ‘2’ replaced by ‘5’ in between all ‘2’ or vice versa. Subjects have to identify these images. If all are ‘2’ or ‘5’ (see Figure 5.3 (a) and (c)), then the subject needed to press ‘n’. If in the image, one ‘2’ is mixed within ‘5’ (see Figure 5.2 (b)), or one ‘5’ is mixed within ‘2’ (see Figure 5.2 (d)), then the subject has to press ‘m’. The minimum and maximum time delay between two stimuli is 01 and 03 seconds, respectively. Subjects have to respond within 0.5 second. Score one is counted for correct response otherwise zero scores are given. When the task will finish, the ‘Task

completed' message will be displayed on the screen. Accuracy is calculated at the end of the task. Subjects perform two-minute practice trials to become familiar with the task and its results do not include in the score. Figure 5.1 shows the screen shots of the messages displayed in the task. Figure 5.3 shows the images used for the stimuli in the task.

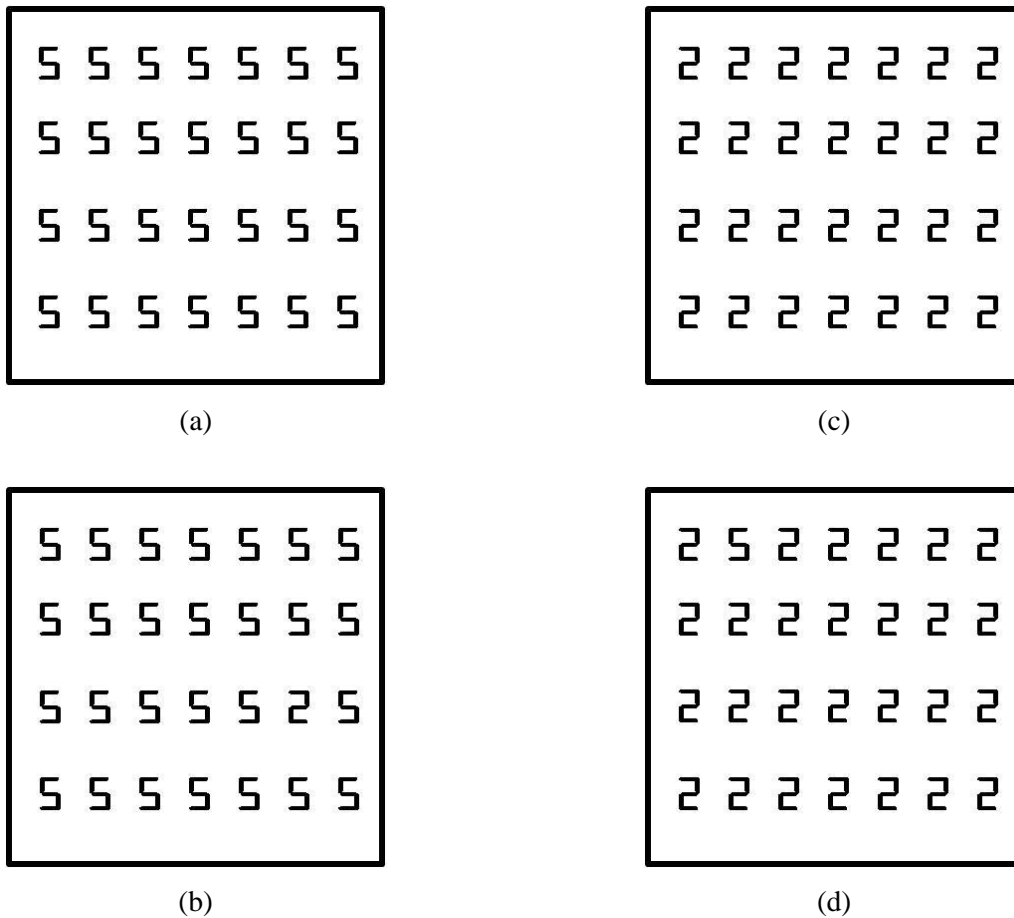


Figure 5.3 Images display in a visual search attention task. (a) Image with all 5 (b) Image with one 2 mixed in all 5 (c) Image with all 2 (d) Image with one 5 mixed in all 2

5.2 Participants

Fifteen healthy subjects (aged 25-29 years) participated in the experiment. All the participants had no history of neurological disease. Participants were informed about the procedure before starting the experiment. Signed informed consent was taken from each participant. Out of 15 participants, two groups were created. 10 participants were randomly selected for the cognitive training named as an active group and no training was given to the remaining 05 participants designated as passive group.

5.3 Stimuli and Procedure

The stimuli were presented on a computer screen with a resolution of 1366×768 pixels and a size of 34×19 cm. Participants were seated in an adjustable chair and asked to find a snug position, from which they would not be allowed to move. The position of the computer screen was adjusted to maintain 80 cm distance from the participants. Participants were made habituated with the computer controls for the tasks. The experiment was divided into three steps, pre-measurement, cognitive training, and post-measurement.

Pre measurement

The measurement of the cognitive capacity of all participants was performed on the first day of the experiment. All the participants performed the four cognitive tasks (explained in section 5.1) and their performance accuracy and response time were calculated.

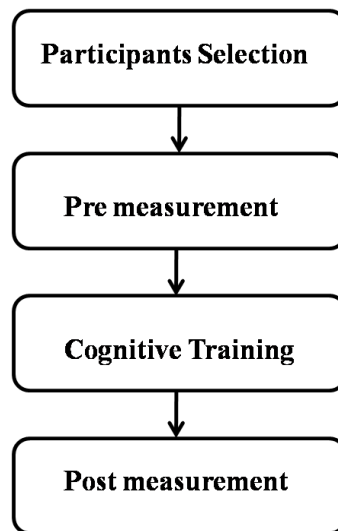


Figure 5.4 Block diagram

Training Intervention and Post 2 measurement

The participants of the active group performed 20 training sessions over four weeks. Training sessions were scheduled each day except weekends which led to five sessions in a week. In each session, the developed cognitive training model (section 3.1) was played for half an hour. A total of 10 hours of training was given to the participants. After the completion of the cognitive training program, post-measurement of the cognitive skills using cognitive tests was performed.

In the post-measurement, the same procedure was followed as pre-measurement. T-test and analysis of variance (ANOVA) were performed to analyze the effect of cognitive training.

5.4 Data Analysis

a) *One-beep attention test*

Statistical analysis was performed on the measures of the one beep attention task, *i.e.* accuracy. Analysis of variance (ANOVA) was used to analyze the effect of the cognitive training between two factors, *i.e.*, test time (pre-test and post-test) and two groups (active and passive group). The effect of the cognitive training was not significant ($p > 0.05$) on the performance of this task. There was no significant difference between the pre and post-accuracies. A t-test was applied between the post-measurement of the active and passive groups and found insignificant ($p > 0.05$) differences between the accuracies of these groups. These results indicate that the task was very easy and didn't create the workload on the brain of participants.

b) *Two-Beep attention test*

Statistical analysis was performed on the measures two measures of the two-beep attention task, *i.e.* accuracy and response time. Analysis of variance (ANOVA) was used to analyze the effect of the cognitive training between two factors, *i.e.*, test time (pre-test and post-test) and two groups (active and passive group). The effect of the cognitive training was found significant ($p < 0.05$) on the performance of this task. A t-test was applied between the pre and post-measurement of the active group and showed a significant 12.65% increase in accuracy. It showed an insignificant ($p > 0.05$) difference between the accuracies of the pre and post-measurement of the passive group.

c) *Left-right attention test*

Statistical analysis was performed on the measures two measures of the two-beep attention task, *i.e.* accuracy and response time. Analysis of variance (ANOVA) was used to analyze the effect of the cognitive training between two factors, *i.e.*, test time (pre-test and post-test) and two groups (active and passive group). The effect of the cognitive training was found significant ($p < 0.05$) on the performance of this task. A t-test was applied between the pre and post-measurement of the active group and showed a significant 17.33 % increase in accuracy. It

showed an insignificant ($p>0.05$) difference between the accuracies of the pre and post-measurement of the passive group.

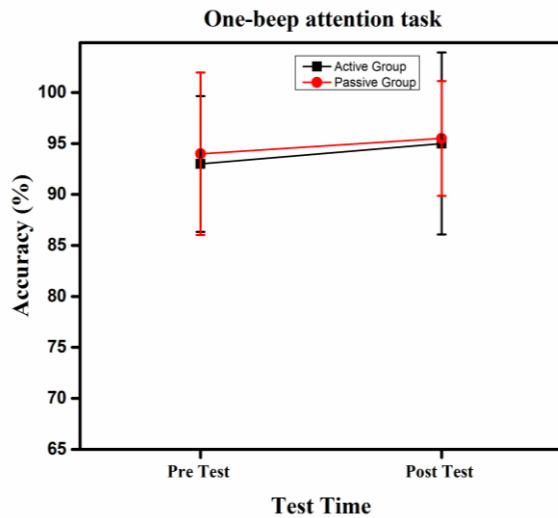


Figure 5.5 Average accuracy in One-beep attention task

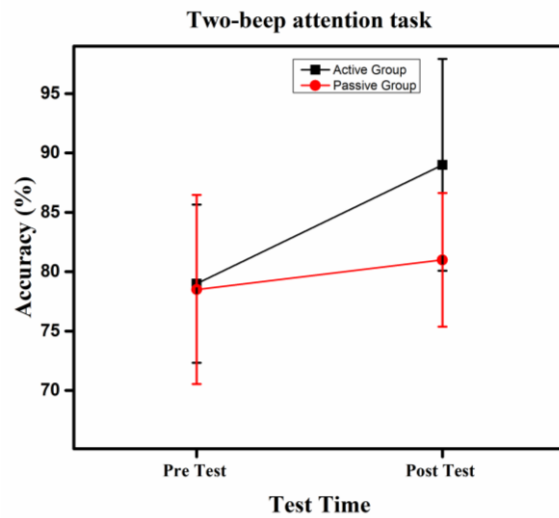


Figure 5.6 Average accuracy in Two-beep attention task

d) *Visual Search attention test*

Statistical analysis was performed on the measures two measures of the two-beep attention task, i.e. accuracy and response time. Analysis of variance (ANOVA) was used to analyze the effect of the cognitive training between two factors, i.e., test time (pre-test and post-test) and two groups (active and passive group). The effect of the cognitive training was found significant ($p<0.05$) on the performance of this task. A t-test was applied between the pre and post-measurement of the active group and showed a significant 14.51 % increase in accuracy. It showed an insignificant ($p>0.05$) difference between the accuracies of the pre and post-measurement of the passive group.

5.5 Discussion

The findings supported the possibility of the estimation of the cognitive capacity using the beep-attention task, left-right attention task, and visual search attention task. The factor to consider is the audio-visual stimuli and it is very important to assess the cognitive capacity in practical scenarios. It is infeasible to assess the cognitive skills with one type of stimuli but cognitive tasks with multiple stimuli seem very important. This concern becomes more significant if our ultimate goal is to bring the technology into real-world applications. It is suggested that

characteristics of the cognitive tasks should be considered for robust and efficient estimation of the cognitive capacity. With these criteria, four cognitive tasks are designed; one-beep attention task, two-beep attention task, left-right attention task, and visual search attention task. These tasks are designed in MATLAB (widely used easily available software) and task difficulty levels can be easily modified.

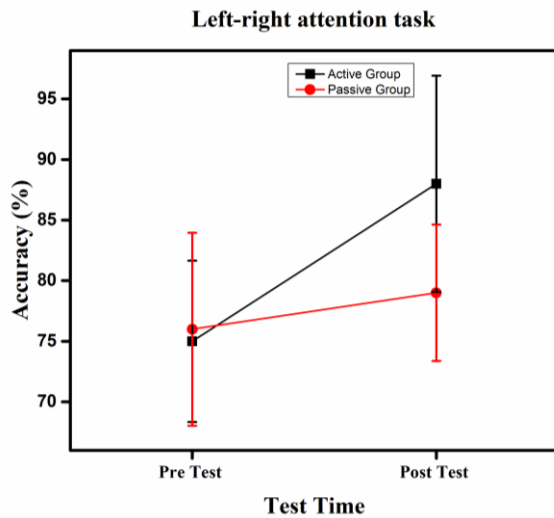


Figure 5.7 Average accuracy in Left-right attention task

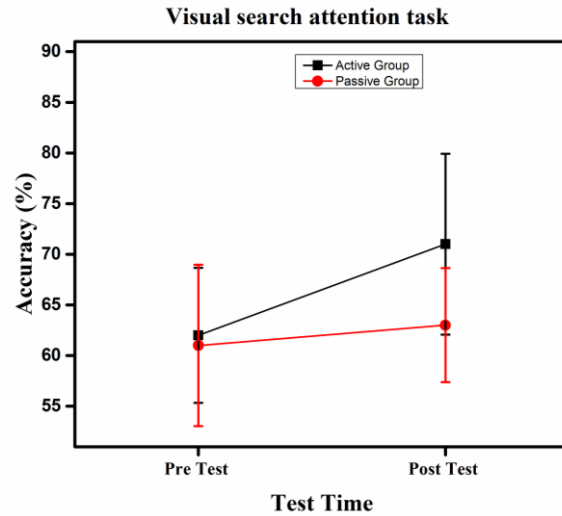


Figure 5.8 Average accuracy in Visual search attention task

In this experiment, we analyzed performance accuracy for estimating the cognitive training effect, with varying the type of the stimuli (audio and visual), for the twenty sessions of the training over four weeks. The features included in our cognitive tasks showed a similar change to those previously reported for attention tasks. The tasks created a different type of workload on the brain. We calculated the accuracy in the task for the participant which is the ratio of the correct response to the total number of stimuli. In the one-beep attention task, no significant change was observed while in the other three tasks, a significant increase in the accuracy of the post-measurement was observed. These observations support that three cognitive tasks were properly devised to measure cognitive capacity.

From our experimental results, it was observed that the attention task based on the beep sounds that enforce participants to respond to audio stimuli immediately with time constraint. The results of the one-beep attention task did not show improvement after the cognitive training. It was also observed that the accuracy in the pre-measurement of this task is very high (>90%). It

can be concluded that the difficulty level of this task was very small and features associated with this task were not strong enough to create the workload on the subjects. Whereas, two-beep attention task showed the improvement in the attentional capacity of the subjects. The left-right attention task also showed similar results. The findings of this test showed that the subject's attentional capacity to divide attention in the visual stimuli is also increased. And, the results of the visual search attention task showed an improvement in attention after the cognitive training.

The results suggested that this training enhanced the capacity to identify the target in the large visual space. The subjects can identify the target very easily in the presence of similar nontargets. It concluded that the features associated with these tasks were strong enough to create the workload on the brain. The participants adapted to task difficulty through cognitive training so that workload induction became easy compared to the pre-training measurement. It was clear to figure out that cognitive training resulted in relatively more user adaptation to the level of difficulty. Nevertheless, we believe that the results presented in our study may help understand the impact of tasks and design for cognitive training, especially in practical situations with limited instruction about the cognitive tasks. Also, it is desired to use more subjects to generalize the results of cognitive tasks. To develop robust models of workload, it is important to build a large database from a large population of subjects performing diverse cognitive tasks. These tasks should be further calibrated for each user to support more accurate real-time workload estimation. Thus, we will further explore the pragmatic configuration of cognitive tasks with a larger number of populations by using the comprehensive comparative scheme.

This chapter explained the design of the four cognitive tasks to understand the effect of audio-visual stimuli. Then, it described the participant's selection, type of stimuli, and procedure used to obtain the effect of the stimulus. It was observed that the audio and visual stimuli affect cognitive performance and found significant improvement in cognitive skills after the cognitive training.

CHAPTER 6

Conclusion and Future Scope

6.1 Conclusion

The present research work aims to enhance the cognitive skills of the sports players and their effect through psycho-physiological changes. Different factors such as background noise, the field of view, and the number of nearby players influence cognitive ability. The cognitive training model was developed and incorporated the factors that influenced the cognitive skills. The effect of cognitive training was analyzed using controlled experimentation. The psycho-physiological measurements provide suitable evidence of enhancement in cognitive skills. Considerable results suggest that cognitive training effectively modulates the EEG waves and improves the performance in psychological tests.

EEG signals have low amplitude and are easily affected by the artifacts. The artifacts may overlap the EEG signals and it is very important to save the original information during the process of artifact rejection. EEG signals were recorded using Emotiv Epoc (14 channel EEG system) while playing the MOT task. All the needful information is obtained from the sub-frequency bands of EEG, *i.e.*, theta, alpha, and beta,*etc.*, and decomposed using wavelet transform. The combination of independent component analysis and wavelet transform is used to obtain a clean signal (D1) from the raw data (R). Artificial noise was added to D1 and again denoised (D2) using the same procedure. Several types of wavelets are available and each has its characteristics. The properties of wavelet function and signal to be analyzed should match. The analysis was performed using 109 wavelet functions from Daubechies, symlets, coiflets, haar, dmeyer, biorthogonal, and reverse biorthogonal families. The bior3.1 exhibited the highest correlation (0.9975) and energy retain (0.965) between D1 and D2. Four features of D1 were calculated and bior3.1 showed maximum energy (21.650×10^7), root mean square (14.81), power spectral density (7.2×10^3), second in minimum skewness (0.08753), and maximum classification accuracy for clean and contaminated signal (91.68%). The results concluded that bior3.1 attributed the highest similarity with recorded EEG signal and selected to perform denoising and decomposition.

Secondly, the effect of the cognitive load on the brain signal was explored in the MOT task. Participants' performance was evaluated in four levels with varying targets 2 to 5 in four levels (L1-L4). The task performance declined with the cognitive load from 98.7 ± 3.1 to $81.8 \pm 18.73\%$. The variation in the EEG of the 14 channels was examined. The results showed the significant changes ($p < 0.05$) were observed in level 1 (- 11.07 to 1.91%), level 2 (- 3.13 to - 14.51%), level 3 (- 6.33 to - 19.46%) and level 4 (- 8.10 to - 20.88%). The results showed a direct relationship between the variations in brain signals with cognitive load. The results of the EEG processing suggested that more activation occurred in the frontal region of the cortex during the MOT task. The frontal region was associated with working memory and attention.

Further, the relationship between alpha, beta, and theta waves with cognitive load was observed. Also, the effect of the cognitive load on the individual cognitive capacity was studied. Participants performed the d2 attention test and divided into three groups (high, medium, and low performers) using the ward method. The increase in theta, decrease in alpha and beta activities was observed with an increase in cognitive load. The results suggested that the high performer group has high cognitive capacity compared to the medium and low performer group.

Thereafter, the effects of cognitive training on cognitive skills were explored. Participants were divided into three groups; active group (players, training group), passive group (players, non-training group), and control group (non-players). The psycho-physiological measurement was performed before the training session. Six psychological tests (Corsi., digit span, two-back for working memory and stroop, identification, continuous performance test for attention) were used to test the cognitive skills. Also, the EEG signals were recorded while playing the MOT task. The PSD and partial direct coherence (PDC) were measured from the EEG signals. The results concluded that players have more cognitive ability as compared to non-players. The alpha coupling strength of players was higher by 47.5% than the non-players. Then, cognitive training was given to the active group for the four weeks (20 sessions, five sessions per week) and after that, post-measurement was performed. The comparative analysis of the pre and post-measurement showed the enhancement in the cognitive skills of the active group even in the presence of the disturbing factors. The psychological measurement showed an increase in the working memory and attention of the active group. After the training, 39.40% decrease in theta, 30.73% increase in alpha, 21.69% increase in the beta of the frontal region, and a 55% increase in alpha coupling strength was observed. Whereas no differences were observed in the passive

and control group. The desynchronization in theta is related to decreasing workload. The synchronization in alpha and beta is related to an increase in attention capacity and working memory. The increase in coupling strength showed a decrease in workload. The increase in alpha and beta waves suggested that the training reduced the effect of background noise, a field of view, and several subjects. Thus, cognitive training reduced the influence of disturbing factors and enhanced cognitive skills.

The longevity effect of cognitive training was also explored. Post2 measurement was performed after three months. Theta increased by 24.95%, which showed an increase in workload. The desynchronization of alpha (14.86%) and beta (11.82%) showed a decrease in working memory and attention. The alpha coupling strength was also decreased by 22.58%. It was observed that the cognitive skills of the active group were decline. The effect of cognitive training was time-limited. The effect of the cognitive training on the audio and visual interferences was also explored. Four cognitive tests (one-beep, two-beep, left-right, and visual search tests) were designed to measure cognitive skills. Two groups of participants were selected; active (training) and passive (non- training) groups. Both groups performed the cognitive tests before the training and cognitive training was given to the active group (20 sessions). Thereafter, post-training measurement was performed. A one-beep test showed insignificant changes between pre and post-measurement. It concluded that the difficulty level of this task was not strong enough to create the workload on the subjects. Two-beep, left-right, and visual search tests showed the 12.65%, 17.33%, and 14.51% significant increase in cognitive capacity of the subjects after the training. The results concluded that the subject's attentional capacity to divide attention in the audio and visual stimuli increased. It suggested that the cognitive training model is efficient to increase cognitive skills and helped to reduce the effect of the interferences.

6.2 Future Scope

Although this research work has a significant contribution in the cognitive training domain to enhance cognitive skills, still there are possible extensions that can be undertaken as potential future work. Few of the future work are listed below:

- i) EEG data is recorded using the 14-channel system. The high-density EEG data acquisition system can be helpful in more rigorous analysis.

- ii) Future work will need to examine the efficacy of the training model using a big sample size. The research work can be extended to explore the effects of the training model on female and aged group players.
- iii) The present research involved soccer players. It will be more attractive for future studies to explore the effects of the training model on other sports.
- iv) In future studies, more factors can be identified those affect the functioning of cognitive skills and can be incorporated into the training model.
- v) It will be more interesting to analyze the effects of training on other physiological factors like heart rate variability, galvanic skin response,*etc.*

List of Publications

Journal Publications

- Ashish Aggarwal and Ravinder Agarwal, Uncertainty assessment in cognitive load for multiple object tracking based on EEG, MAPAN-Journal of Metrology Society of India, pp. 1-9, 2019
- Ashish Aggarwal and Ravinder Agarwal, Optimal determination of wavelet for football player EEG using SVM classifier, Biomedical Research, Allied Academies, vol. 29, no. 2, pp. 218-226, 2018
- Ashish Aggarwal and Ravinder Agarwal, “Comparative analysis of theta, alpha and beta wave in the assessment of cognitive load and individual differences” Applied Psychophysiology and Biofeedback, Springer (Communicated)
- Ashish Aggarwal and Ravinder Agarwal, “Co-efficient of variation-based performance analysis of multiple object tracking” Heliyon, Cell press (Communicated)
- Ashish Aggarwal and Ravinder Agarwal, “An EEG based evidence of enhancement in cognitive skills through cognitive training” Cognitive Processing, Springer (Communicated)

Papers presented in National and International Conferences

- Ashish Aggarwal and Ravinder Agarwal, Classification of the cognitive load in multiple object tracking task using SVM classifier based on EEG, 10th International conference on Advances in Metrology, Feb. 20-22, 2019, National Physics Laboratory, New Delhi, India.
- Ashish Aggarwal and Ravinder Agarwal, Cognition and sports: A review, 4th National Conference on Advances in Metrology, February 23-25, 2014, Thapar University, Patiala.

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