Impact of Motor Imagery and its Ability on Learning of Consecutive Motor Tasks

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Declaration

I certify that this research work titled "***Impact of Motor Imagery and its Ability on Learning of Consecutive Motor Tasks***" is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

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Dedicated

To

My Father

Whom I know as strongest of all people that I ever came across, who taught me how to believe in myself and to push beyond the impossible

My Mother

Most innocent of all souls who believes on all my weird decisions and logics

Dr. Muhammad Nabeel Anwar

Who has been more than just a supervisor for me and gave me important life lessons just like a friend would do

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For being my antidepressant in all my low times

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Zaeem Hadi

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ABSTRACT

Background: Motor learning is improvement of motor performance through motor imagery or physical practice. Motor imagery of a motor task is a symbolic rehearsal of a task without any overt motor output and it assists a person in mentally preparing for performing a task. Due to its effectiveness, it has widely been used in rehabilitation of sports injuries in athletes and of stroke-effected patients.

Objective: Current study was to investigate the impact of motor imagery of one motor task on learning of second motor task. In addition to that, our aim was to find out if kinesthetic motor imagery ability of individuals has any correlation with task performance of second motor task.

Methodology: Bimanual finger tapping task was selected for motor imagery practice and a button press task was selected to evaluate the effect of tapping practice using motor imagery. 13 subjects were considered for analysis. These subjects were categorized as "ITNF+B". They performed motor imagery (I) of tapping task (T) with no-feedback (NF) and button task (B). The group was compared with previous available data of groups TF+B, TNF+B and B. TF+B performed tapping with feedback and button task. TNF+B performed tapping without feedback and button task. B group performed only button task.

Results: One-way ANOVA shows presence of significant difference between all groups in early learning stage with $F(3,48)=5.0874$, $p<0.05$. Applying Tukey test for post hoc analysis shows a significant difference of groups TF+B with B and ITNF+B with B in early learning stage. In addition, there was a significant difference between all groups in late learning stage with $F(3,48)=7.2271$, $p<0.05$. Applying Tukey test for post hoc analysis shows a significant difference of groups TF+B with B, TNF+B with B and ITNF+B with B. Correlation of individual motor imagery ability with performance scores of button task resulted in negative correlation in both early and later stages of learning with $r = -0.2768$ and $r = -0.6889$.

Conclusion: This study suggests that previously learned behaviors using motor imagery can facilitate the learning of new motor behaviors. In fact, imagery practice of a motor behavior yields better results in learning of new behavior as compared to actual practice. Moreover, imagery score of an individual, after practice of one motor behavior modulates the learning of a new behavior.

Keywords: *Neuroplasticity, motor learning, motor imagery, kinesthetic imagery, bimanual finger tapping, feedback*

PART I

INTRODUCTION & LITERATURE REVIEW

1 Neural Plasticity

1.1 Definition

Central nervous system communicate with each other through neurons.Neurons are connected to each other with axon and dendrites. Input from various senses modifies the strength of these connections[1]. Neuroplasticity can be described as:

"*Neural plasticity can be defined as the ability of the central nervous system (CNS) to adapt in response to changes in the environment or lesions*".[1]

This adaptation ability of CNS helps in successfully coping to environmental challenges by involving new neural networks or by modification of already present connection strengths for brain areas associated with that particular task(i.e., movement, language, vision, and hearing). Neural plasticity occurs throughout the life span[1].Neuroplasticity employs various mechanisms, which not only involves increase in strength of connections that are already present but also the formation of new neurons[2].Cramer gives another description of neural plasticity involving structural and functional changes based on both internal and external environmental changes:

"*The ability of the nervous system to respond to intrinsic or extrinsic stimuli by reorganizing its structure, function and connections*."[3]

1.2 Types of Neuroplasticity

1.2.1 Structural and Functional Plasticity

Neuroplasticity occurs in both functional and structural forms, where structural plasticity is associated with change in amount of gray matter and functional plasticity involves increased amount of activation in associated brain areas.[4]

1.2.2 Short-Term and Long-Term Plasticity

Plasticity can be short lived which is termed as short-term synaptic plasticity lasting only for milliseconds to minutes. This short-term plasticity plays major role in short-term adaptations and short-lived memory formation.[5]Long-term potentiation (LTP) and long-term depression (LTD) are another two forms of neuroplasticity.LTP is activity dependent plasticity that results in long lasting enhancement of synaptic transmission whereas LTD is exact opposite of that. LTD results in reduction of efficacy of the synaptic transmission.[6] LTP cannot work alone as it only works to enhance the synaptic transmission therefore LTD is required to bring down the synaptic strengths to avoid saturation.[7]LTP and LTD are involved in various experience dependent functions which also includes learning and memory.[8]Synaptic plasticity is considered a major mechanism of memory formation and it helps in information storage for the brain region involved in the activity.[9]

2 Motor Learning

2.1 Definition

Motor learning is the acquisition of new skills through practice and the acquired skill is relatively permanent which is different from performance in which the skill execution results in temporary change[10]. Schmidt defines motor learning as:

"*A set of processes associated with practice or experience leading to relatively permanent changes in the capability for responding.*"[11]

Motor learning not only helps in acquiring new skills but also in relearning of previously acquired skills.[12]

2.2 Characteristics of Motor Learning

Motor learning has various characteristics. First is that even after attaining capability to perform the skill, the execution and performance of skill can be effected by environmental factors such as weather, motivation of the performer or fatigue. Second characteristic of motor learning is that it occursonly because of practice. Motor learning does not occur because of maturation, which is motor development (e.g. learning to walk) and not motor learning. Third characteristic of motor learning is that it cannot be observed directly but can only be measured in terms of performance as it brings a relatively permanent change in a person's behavior.[10]

2.3 Stages of Motor Learning

Learning of a motor skill involves a process, which is composed of three stages. The three stages are described below.

2.3.1 Cognitive Stage

Cognitive stage is the early stage of motor learning. During this initial stage learner develops an understanding of the skill and the objective of the skill being performed.[13]The learner has to consciously perform the movement and learn through experimenting different strategies to produce optimized result. Because of these complex requirements, the learner's performance is usually abrupt and slow. Moreover, they lack any kind of consistency in their performance.[14]

2.3.2 Associative Stage

In this stage learner begins to perform movement that is more refined. Learner focuses on performing efficient movement and moves from a state of "what to perform" to "how to perform". Learner becomes more dependent on proprioceptive sensation while performing the skill and less dependent on visual cues.[13]

2.3.3 Autonomous Stage

During the autonomous phase of motor learning, the movements performed by the learner are more fluent with close to zero errors.This stage is also termed as motor stage as learner tends to perform seemingly effortless motions.[15]Learner requires a lot less effort in this stage because the attentional demands are largely reduced in this stage. Movements performed by the learner are less conscious and more autonomous.[14]

2.4 Types of Motor Learning

Motor learning is divided into various types based onthe learning and stabilizationmechanisms, which are given below.

a. Explicit Learning
b. Implicit Learning
c. On-line Learning
d. Off-line Learning

2.4.1 Explicit Learning

Explicit learning is also termed as "Declarative learning". This type of learning requires active attention and awareness of learner as it involves remembering a series of events or facts. Thus, explicit learning make more demands on working memory.Learners are aware in this case about what they have learned and they can verbally explain the knowledge gained.[16] Practice of a particular task can transform the learning mechanism from explicit to procedural or non-declarative.[17]

2.4.1.1 Process of Explicit Learning

Explicit learning process is composed of four distinct steps that are given below.

2.4.1.1.1 Encoding

Encodingis the process or set of processes through which a new information is manipulated when it is encountered for the very first time.The encoding later serves as the very basis of how one remembers that information when it is required again. For an information to be stored for relatively long period, the encoding must be comprehensive and detailed. This can be achieved by integrating new information systematically to the already present information in a conscious manner.[18]

2.4.1.1.2 Consolidation

Consolidation is the manipulation of the already gained information to make it stable for long-term usage.[18]

2.4.1.1.3 Storage

Storage is the process through which a piece of information is retained for a long period. This long-term storage is unlimited in comparison to short-term memory that in fact is very limited.[18]

2.4.1.1.4 Retrieval

Retrieval works to make the required stored information available for use. Various kinds of information need to be integrated during retrieval and each information is stored at separate storage sites. Retrieval works best when the information is required in the same context in which it was stored and in the presence of same conditions and cues which were present when information was obtained.[18]

2.4.2 Implicit Learning

“Implicit learning” or “Declarative knowledge” is a type of learning in which learner is unaware of the knowledge that they have gained which although is quite evident from their behavioral performance. Learners cannot verbally explain in this case what they have learned.[16]

2.4.2.1 Types of Implicit Learning

Implicit learning is further classified into three types that are explained below.

2.4.2.1.1 Non- Associative Learning

Non-associative learning is modification in the strength ofresponse to a single event or stimulus due torepeated exposure to that stimulus.[19] Non-associative learning is further divided into two types based on modification of response strength.

2.4.2.1.1.1 Habituation

Habituation is a decrease in the response strength to a particular stimulus after multiple presentations. This could be because one learns that consequences of the stimulus are neither harmful nor rewarding.[19]

2.4.2.1.1.2 Sensitization

Sensitization in contrast to habituation refers to the process in which repetitive exposure to a single event or stimulus results in increase of response strength.[19]

2.4.2.1.2 Associative Learning

Associative learning is form of implicit learning in which an individual establishes a relationship between two different stimuli or between a stimulus and a particular event. Associative learning has been classified in two types based on the process used for learning that are described below.[18]

2.4.2.1.2.1 Operant Conditioning

Operant conditioning is trial and error based learningin which one associate a certain response with a consequence. In other words, operant conditioning is a cause and effect relationship between an organism's behavior and the resulting consequence of the behavior. The behavior that tends to produce changes in environment that are more favorable (i.e. generation of reward or removal of noxious stimuli), is more likely to be repeated and the behavior that results in negative consequences are less likely to be reproduced. Operant conditioning involves behaviors that occur spontaneously or when a stimulus is not specifically identifiable.[18, 20, 21]

2.4.2.1.2.2 Classical Conditioning

Classical conditioning is association of a relationship between two different stimuli.[18] In classical conditioning, an unconditioned stimulus (which produces behavioral response) is paired with a neutral stimulus (which does not produce any response individually).Because of the paring, the behavioral response starts to occur in result of the neutral stimulus also. Previously neutral stimulus is termed as conditioned stimulus and the response that is generated as a result is called conditioned response.[22]

2.4.2.1.3 Procedural Learning

Procedural learning is a type of implicit learning in which a person does not require attention and awareness and automatically learns a particular task because of repetition of the task in continuous manner (e.g. as Human's learn walking).

2.4.2.2 Characteristics of Implicit Learning

Characteristics of implicit learning given below helps in differentiating between implicit and explicit learning.

2.4.2.2.1 Transfer Specificity

Transfer specificity is considered main characteristic of implicit learning according to which knowledge acquired through implicit learning is not flexible and strictly connected to the characteristics of stimuli.[23, 24] Some other aspects to transfer specificity are as follows.

2.4.2.2.1.1 Relative Inaccessibility of Knowledge with Free Recall

In implicit leaning, knowledge gained by learners is unexplainable. The knowledge learned is stored by it is not freely available to recall as learners have gained knowledge unconsciously. The availability of knowledge is associated with set of particular stimuli.[23, 25]

2.4.2.2.1.2 Relative Inaccessibility of Knowledge with Forced-Choice Tests

Since implicitly gained knowledge is not freely available to recall so other methods have been employed to assess the acquired knowledge. Forced-choice tests are one of those techniques. Although forced-choice tests can be used to identify the knowledge gained, however, it is not clear that force-choice tests depict explicit learning or implicit learning.[23]

2.4.2.2.1.3 Limited Transfer to Related Tasks

Knowledge gained through implicit learning is not transferred to other structurally similar tasks. Performance level in similar tasks are not same and they tend to decline.[23, 25]

2.4.2.2.2 Associated withIncidental Learning Conditions

Implicit learning is more related to incidental conditions. If one tries to figure out the purpose of task explicitly, they will not be able to perform as well as those whose approach of task performance is more implicit.[23-25]

2.4.2.2.3 Increase in Utilization of Intuition

People makes responses based only on the intuitive feeling and they may believe that they are simply guessing instead of actively working out to get an answer. This state arises due to implicit learning and supports an individual in making decisions.[23, 26]

2.4.2.2.4 Robustness

Knowledge gained through implicit knowledge is considered robust and any manipulations to that knowledge will effect it differently in comparison to explicitly learned knowledge.[23-27]Reber has suggested that implicit learning is more robust as compared to explicit learning.[26] Some other aspects to this are as follows.

2.4.2.2.4.1 Time

Knowledge gained through implicit learning shows longer retention period than knowledge gained through explicit learning.[23]

2.4.2.2.4.2 Psychological Disorder

Implicit learning remains intact as compared to explicit learning in case of a psychological impairment. In addition, the implicit learning of patients is same as those of normal persons.[23-25, 28]

2.4.2.2.4.3 Secondary Tasks

Implicit learning of a task is less affected by addition or presentation of a secondary task as compared to explicit learning.[23-25]

2.4.2.2.4.4 Age Independence

Implicit learning is relatively unaffected by age and development as compared to explicit learning.[25]

2.4.3 On-line Learning

On-line learning is also called the fast learning phase of a particular skill in which significant performance improvements can be observed after short time of practice (in order of seconds to minutes).[4, 29, 30]

2.4.4 Off-line Learning

Off-line learning is also called the slow learning phase of motor skill learning. It can also be termed as consolidation or retention of learning which can be observed by re-performing the same task after a relatively long period.[4] A significant difference in learning is observed after a period of about 4 hours.[31]

2.5 Motor Learning Tasks

There are number of motor learning tasks that are widely used to understand the processes underlying various behaviors. Details of some are given below.

2.5.1 Serial Reaction Time Task

Nissen and Bullemer first developed serial reaction time task (SRTT) in 1987 which is a form of sequential learning.[32]In SRTT task subjects performed a particular type of movement based on the visual cue presented on a computer screen.The end of movement marks the completion of trial. Time that a subject takes to complete the movement is measuredas reaction time. The series of reiterating sequences are followed by a short delay after which some random trials are presented.[33] Although SRTT's are widely used however they have a limitation that only performance evaluation is based on only one measure (i.e. response time).[34]

2.5.2 Sensorimotor Adaptation

Martin has defined motor adaptation as trial-to-trial and error feedback based movement modification. Some of the parameters of movement (e.g. force, direction) are modified however; its identity or specificity is maintained (e.g. reaching task). Change in the movement is gradual and occurs only because of repetition of some particular behavior. In addition, once adapted, one cannot perform the movement in previous manner and must de-adapt with practice in same gradual manner.[35] Though adaptation is not motor learning however repeated adaptation results in learning of new motor behavior.[36] Sensorimotor adaptation tasks can be used in different forms for trial and error based learning some of which are visuo-motor learning tasks, point to point ballistic reaching movement tasks, force-field adaptation and locomotor adaptation.

2.5.3 Finger Tapping Task

Finger tapping tasks are widely used in functional neuroimaging studies of better understanding of human motor system. These tasks have various variations based on presence of externally generated pacing stimuli. Pacing stimuli is to make sure that all subjects perform at uniform predefined rate. Stimuli can be either auditory or visual. These tasks can also be performed without the presence of any externally generated stimuli. These self-paced tasks are termed as internally guided or internally generated.[37]

3 Motor Skill Learning Induced Plasticity

Numerous studies have been carried out to establish a relationship between plasticity and motor skill learning. An fMRI study has shown that M1 regions shows increased amount of activation during acquisition (fast learning) that was further increased representing retention (slow learning).[38] In early stages of motor skill acquisition brain activity is modulated in the dorsolateral prefrontal cortex (DLPFC), primary motor cortex (M1) and pre supplementary motor area (preSMA) that shows decreased activation as learning progresses [4, 39, 40] whereas in premotor cortex, supplementary motor area (SMA), parietal regions, striatum and the cerebellum brain activation is increased as learning progresses.[39, 41, 42]Slow learning is associated with increased amount of brain activation in regions of M1, primary somatosensory cortex, SMA and putamen.[39, 43] In addition to functional plasticity, motor skill learning also results in structural plasticity of different brain regions. Various longitudinal and cross-sectional studies have shown that density of grey and white matter in different regions of brain is modulated with motor skill learning.[4] A study has reported that judo players has greater gray matter volume in frontal, parietal, occipital and temporal lobes as compared to control subjects.[44] Large volumes of grey matter have also been observed in vermian lobules I-V of world class mountain climbers as compared to their equivalent aged controls which could be because of increased hand dexterity and hand-eye coordination.[45]A difference in hand motor area between musicians and non-musicians has been observed. Hand motor area was larger in professional musicians as compared to non-musicians.[46]

4 Motor Imagery

4.1 Definition

Motor imagery is also termed as mental practice or mental training. Motor imagery is the mental simulation of the actual task without actually performing the task. Richardson has defined it as:

"Mental practice refer to the symbolic rehearsal of a physical activity in the absence of any gross muscular movements"[47]

In other words, motor imagery represents a physical movement but without any kind of actual motor input involved.Motor imagery includes the phase of action preparation and imagining a previously performed action.[48] Action observation is also used for rehabilitation along with motor imagery but they are two separate techniques and should not be confused.[49]

4.2 Types of Motor Imagery

Motor imagery is of two types based on the type of imagination.

4.2.1 Kinesthetic Motor Imagery

Kinesthetic motor imagery is associated with the imagination of sensation and feelings of the movement performed without any muscle tension.[50]

4.2.2 Visual Motor Imagery

Visual motor imagery has further two forms based on the first or third person's perspective. From first person's perspective, the person imagines or visualizes himself performing the movement whereas from third person's perspective, the person imagines or visualizes some other person performing the movement.[51]

4.3 Motor Imagery Induced Plasticity

According to Lotze and Cohen, motor imagery involves the activation of brain regions that are also activated during motor execution.[52] Brain activation followed by motor imagery is not associated with generalized muscle involved in the movement and is movement specific.[53] A motor imagery study on pianists showed that during motor execution and motor imagination same motor regions were activated with the exception of primary sensorimotor area in the left hemisphere and right cerebellum.[54]Lacourse suggested that plasticity is induced as a result of mental practice of a sequential motor learning task.[55]Although most of the motor imagery studies focus on hand, finger or mouth movements, this does not imply that motor imagery does not activate brain regions associated with gross movements. Activation of pre-supplementary motor areas and primary motor cortex has been reported as a result of gross movements.[56]Jeannerod has talked about simulation hypothesis which states that motor imagery and action observation employs the same mechanism which is used during motor execution.[57]On physiological and behavioral basis, motor imagery results in the increased EMG activity of the muscle involved as compared to others which has been evident in studies involving athletes and musicians.[58] The amplitude and frequency of the EMG is found to be greater during the kinesthetic imagery as compared to visual imagery.[59]Increase in heartbeat and respiratory rates have also been observed during motor imagination.[60, 61]Evidence based on all these studies strongly suggests that motor imagination of a task involves many anatomical regions that are also involved during motor execution but these regions are not completely overlapping.[58] M1 area is missing from the overlapping regions that can be explained as system's mechanism to avoid any overt movement.A functional study has shown that despite imagery and execution activates overlappingbrain regions but the functionalrelationship between them is not significant and the networks employed are not identical.[59]

4.4 Relationship between Motor Imagery and Motor Skill Learning

Motor imagery is also considered an offline operation of motor system. Use of motor imagery has widely been reported in sports by athletes for learning and re-learning of motor skills for performance enhancement.[51]Vandell showed that performance improvement because of motor imagery in basketball free throws was equivalent to physical practice of the free throws.[62] Clark showed in another study that performance of motor imagery group was equivalent to the performance of group with physical practice only and that the combination of motor imagery and physical is much better for motor skill learning.[63]It has beenestablishedthrough a previous study that repeated motor imagery helps in learning of movements and imagery using first person's perspective produces better results.[64, 65]Motor imagery is not just useful in sports domain. A study showed increase in performance of piano players of both motor imagery and motor execution groups, with motor execution group outperforming the imagery group; the difference in performance disappeared after one additional session of imagery group.[66] Another interesting relationship has been established between motor imagery and muscular strength which suggests that muscular strength is increased as a result of mental training.[67]Motor imagery is effective for not only short-term but also long-term motor skill acquisition. Feltz and Landers suggested that motor imagery not only helps in early stages of learning but it also helps in later stages.[64]

4.5 Comparison of Kinesthetic and Visual Imagery

Many of the previous studies have confused kinesthetic imagery with visual imagery's first type. Visual imagery from first person's perspective is different from kinesthetic imagery. In kinesthetic imagery, a person tries to imagine himself performing the movement and feel the sensation associated with movement whereas in case of visual imagery from first person's perspective, only self-visualization is required without the kinesthetic experience.

Various studies have described the difference in brain regions involvedduringeach types of imagery.Motor tasks involving hand coordination and precision of time produce better results using kinesthetic imagery as compared to visual imagery that is more associated with spatial parameters.[68] Kinesthetic imagery produce more effective results in close motor learning tasks as compared to visual imagery that is more effective in case of open motor learning skills.[69]Visual imagery is more effective in retention of tasks that involves production of complex patterns of movements whereas kinesthetic imagery supports more accuracy-focused tasks.[70-72] While it is difficult to explain the kinesthetic imagery, it is not the case with visual imagery. Kinesthetic imagery takes longer time depending on task complexity in accordance with Fitt's law whereas visual imagery does not.[48] There has been observed activity in muscle involved in kinesthetic imagery however no activity occurs in case of visual imagery.[53]

4.6 Methods for Measuring Motor Imagery Ability

4.6.1 Motor Imagery Questionnaire (MIQ)

Motor imagery ability of an individual can be measured using various methods. One of the earliest methods was designed in 1983 that is known as "Motor Imagery Questionnaire (MIQ)". MIQ has a total of 18 questions in which 9 are visual imagery questions and 9 are kinesthetic imagery questions. MIQ however does not measure the motor imagery ability directly. MIQ measures motor imagery ability of a person in terms of one's easiness to imagine a certain movement. The movement was rated on a scale of 1 to 7 where 1 represents very easy and 7 represents very hard to imagine. Subject is instructed to assume a particular position first. He is described about the movement that needs to be performed and is then asked to perform the movement. The subject then returns to normal position and imagines performing the movement. At the end the subject rates the easiness of imagination on a scale of 1 to 7.[73]

A shorter form of MIQ was later developed in 1997, which included only eight imagery questions (four for each type of imagery). Another change in MIQ-R was that rating scale was reversed with 7 replaced as being easiest to imagine and 1 being very hard to imagine.[74]

4.6.2 Vividness of Motor Imagery Questionnaire (VMIQ)

Vividness of motor imagery questionnaire (VMIQ) was developed after MIQ. VMIQ measures the the clarity with which one can imagine a particular movement. VMIQ has a total of 48 (24 for each type of motor imagery) questions in which subjects have to rate on a scale of 1 to 5, where 1 means "as clear as normal vision" and 5 means "no image". In contrast to MIQ, subjects were not required to perform the movement before imagining it.[75]

4.6.3 Kinesthetic and Visual Imagery Questionnaire (KVIQ-20)

KVIQ-20 was developed for subjects that required guidance to perform and rate the movement. It does not involve any full body movements and subject performs all the movements in seated position. KVIQ-20 has a total of 20 questions where 10 questions are for visual imagery and 10 are for kinesthetic imagery. The steps involved in performing the movement are same as MIQ. Subjects are required to rate the movement on a scale of 1 to 5 where 1 represents the lowest level of imagery and 5 represents highest.[76]

A shorter form of KVIQ-10 is also available. The only change from KVIQ-20 in KVIQ-10 is that it contains only 10 questions. 5 are of visual imagery and 5 for kinesthetic imagery.[76]

PART II

METHODLOGY

5 Methodology

5.1 Subjects

13 healthy and right-handed university students were recruited as subjects. These subjects. All subjects signed a consent form before participation in the experiment. Participants were given written instructions about the experiment and were briefed verbally. The experiment protocol was approved by the local ethics committee.

5.2 Experimental Overview

The protocol consisted of two sessions. For first session, subjects sat in a comfortable chair with hands positioned according to their comfort. For second session, subjects seated on a comfortable chair placed two meters away from the LCD screen. They were instructed to place their arms on table in order to be able to tap and press a button in comfortable manner. Subjects were studied in the experimental room of Human Systems Lab (HSL), School of Mechanical and Manufacturing Engineering (SMME), National University of Sciences and Technology (NUST) Islamabad.

5.3 Signal Acquisition

The hardware used to acquire the signals was Powerlab by ADInstruments. Powerlab is a multi-purpose device used to acquire various types of physiological signals. It also provide tools to do multi-channel recordings.Data is acquired through the help of a software called LabChart. LabChart is capable of pre-processing the data. It has tools to amplify or filter the acquired signal in real time or during offline analysis.

Figure 1 PowerLab 26T amplifier used for data acquisition

5.3.1 Signal Acquisition of First Task

First task was a motor imagery task in which subjects only imagined the movements and no motor execution was done. So no signals acquisition was acquired during the first task.

5.3.2 Signal Acquisition of Second Task

A pulse transducer of ADInstruments (provided with PowerLab 26T series) was used as a tap detecting sensor. A push button of ADInstruments (provided with PowerLab 26T series) was used as a button-pressing sensor. Outputs from the sensors were fed in two channels of PowerLab. Signals were recorded using LabChart software.

Figure 2 Push Button and Pulse Transducer

5.3.3 Auditory Signal Cue

Audio cue was provided in both tasks using a macro in LabChart 7 software and Samsung earphones were provided for the subjects.

5.4 Experiment Protocol

The experiment was composed of two different tasks. Subjects first performed the tapping task and then the button task.

Subjects were further sub-divided into following groups based on the type of task:

1. **ITNF+B Group:** Subjects in this group performed only the motor imagery of tapping task without any feedback and then the button task.
2. **TNF+B Group:** Subjects in this group performed tapping task without feedback and the button task.

3. **TF+B Group:** Subjects in this group performed tapping task with performance feedback and then the button task.
4. **B Group:** Subjects in this group only performed the button task.

First three groups performed the two task on the same day with the inter task interval of fifteen minutes.

The data of group 2 and group 3 was available from a previous study[77]. In this study, data of group ITNF+B was obtained. The subjects in the group ITNF+B were also tested for their individual kinesthetic motor imagery ability before the experiment using KVIQ-10 questionnaire.

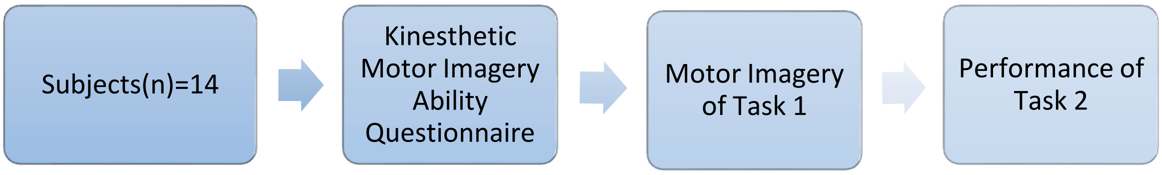

Figure 3 Experiment Flow

5.4.1 Tapping Task

Tapping task in the study was adopted from a study originally carried out by Serrien[78]. During tapping task, participants were seated on a comfortable chair.They were instructed to perform the motor imagery of bimanual tapping.Subject performed the tapping in 2:1 mode in which index finger of non-dominant limb carries out twice the taps as compared to index finger of dominant limb. Tapping takes place in two cycles. During one cycle tapping of index fingers of both limbs is performed. During second cycle, only non-dominant limb's index finger is tapped while keeping the index finger of dominant limb at peak upward position. The subjects were instructed to imagine the tapping in the above-mentioned order.

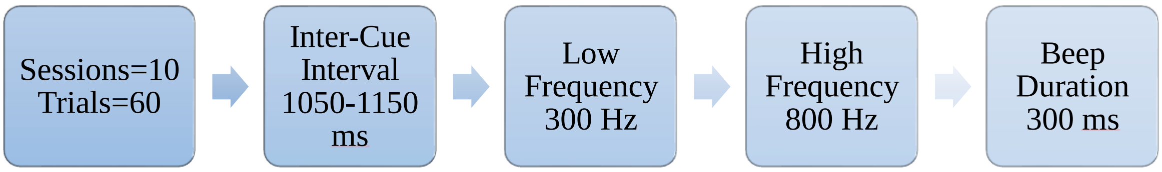

Figure 4 Tapping Task Specifications

Task timing was externally paced and auditory stimulus (beep) was generated in random order to avoid the prediction tapping from the subjects. The randomly generated beep marked the inter trail interval ranging from 1050 ms to 1150 ms. The duration of the beep was 300 ms. The two cycles of 2:1 tapping was differentiated by high frequency and low frequency beep. Low frequency beep was of 300 Hz and high frequency beep was of 800 Hz. Subjects were instructed to tap simultaneously in response to low frequency beep followed by a tap of non-dominant finger in response to high frequency beep. The imagery group performed 10 sessions of tapping task with 60 taps per block.

Figure 5 Motor Imagery of Tapping Task

5.4.2 Button Task

Button task aimed to evaluate the performance after the practice of tapping task. Button task consisted of 7 sessions and each session was composed of 30 trials. Each session was separated by an interval of 1 minute.Transducer for tapping and push button of ADInstruments were used for button tasks in. Subjects were instructed to tap on a transducer with the index finger of the dominant hand and press the push button twice with non-dominant hand in response to the auditory cue. Task B consists of 7 sessions of 30 trials each along with 1 min of break in-between sessions. In each trial subjects were asked to perform tapping on a transducer (ADInstruments, Australia) with the index finger (dominant hand) along with twice pressing the push button (ADInstruments, Australia) with thumb (non-dominant hand) instantly after hearing a beep.

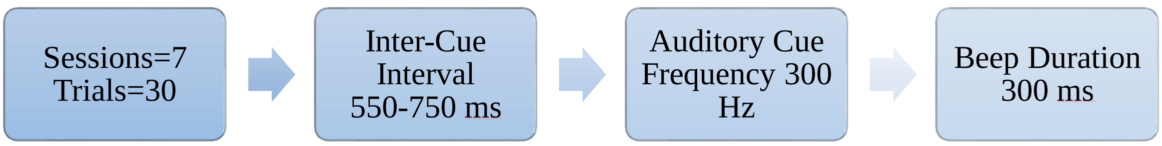

Figure 6 Button Task Specifications

Task timing in button task was also externally paced and auditory stimulus with inter trial interval of 550 ms - 750 ms was randomly generated through a macro in LabChart software. An auditory cue of 1 KHz frequency was generated after 3 seconds that marked the start of the task. Subjects were instructed to tap immediately after hearing the beep and complete the trial before next beep. They were asked to synchronize their tapping with the second button press of the non-dominant hand. Data was recorded in LabChart 7 software.

Figure 7 Button Task Performance

5.4.3 Timing Diagrams

5.4.3.1 Tapping Task (ITNF Group)

Figure 8 Timing Diagram of Tapping Task for motor imagery group

5.4.3.2 Button Task

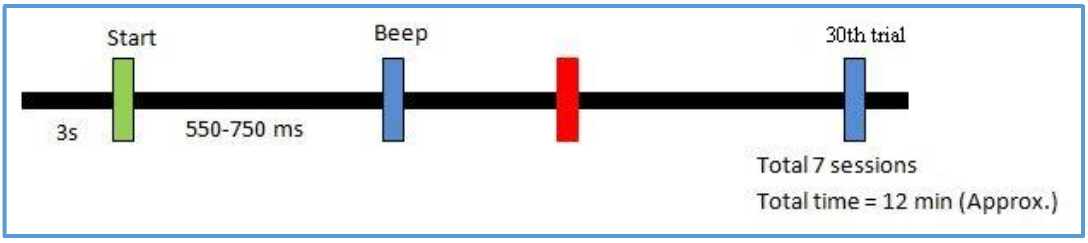

Figure 9 Timing Diagram of Button Task

PART III

RESULTS

6 Results

The data obtained in button task is assessed based on the reduction of number of errors because of practice. Number of correct trials of subjects were termed as score. Data was divided into “Early” and “Late” stages. Early stage is the average of first two sessions whereas late stage is the average of the last two sessions.Statistica software 10 was used to analyze the data. The student t-test for dependent samples was performed on averaged sessions (early, late) of all groups. Multi-group comparisons between groups B, TNF+B, TF+B and ITNF+B were performed using ANOVA. The results were considered significant if $p<0.05$.

6.1 T-test comparisons of all Groups

T-tests between early and late session of each group showed significant difference as $p<0.05$. The average score in each group indicates increased learning in later stages of the task.

6.1.1 B Group

	T-test for Independent Samples (Spreadsheet10) Note: Variables were treated as independent samples								
Group 1 vs. Group 2	Mean Group 1	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2
Early vs. Late	6.730769	14.65385	-2.94647	24	0.007045	13	13	5.433750	8.029593

Figure 10T-test results between early and late stages learning of B group

6.1.2 TNF+B Group

	T-test for Independent Samples (TNF+Bgroup (t_test).sta) Note: Variables were treated as independent samples								
Group 1 vs. Group 2	Mean Group 1	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2
Early vs. Late	10.00000	21.07692	-14.5897	24	0.000000	13	13	1.607275	2.215910

Figure 11T-test results between early and late stages learning of TNF+B group

6.1.3 TF+B Group

	T-test for Independent Samples (TF+B group (t_test).sta) Note: Variables were treated as independent samples								
Group 1 vs. Group 2	Mean Group 1	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2
Early vs. Late	12.73077	21.23077	-16.4571	24	0.000000	13	13	1.033106	1.549400

Figure 12T-test results between early and late stages learning of TF+B group

6.1.4 ITNF+B Group

Group 1 vs. Group 2	Mean Group 1	Mean Group 2	t-value	df	p	Valid N Group 1	Valid N Group 2	Std.Dev. Group 1	Std.Dev. Group 2
	T-test for Independent Samples (ITNF+B group (t_test).sta) Note: Variables were treated as independent samples								
Early vs. Late	13.80769	23.84615	-3.49568	24	0.001862	13	13	8.302957	6.185954

Figure 13T-test results between early and late stages learning of ITNF+B group

6.2 Multi-group Comparisons

Multi-group comparisons were performed using one-way ANOVA between B, TNF+B, TF+B and ITNF+B groups.One-way ANOVA was applied on both early and late sessions of each group.

6.2.1 Multi-group Comparison of Early Stage

One-way ANOVA on early stage sessions of groups B, TNF+B, TF+B and ITNF+B results in F(3,48)=5.0874 and p=0.00387 (p<0.05) which shows that a significant difference in scores exists between these groups. Since ANOVA cannot predict that which two groups differ from each other, so post-hoc analysis was performed using Tukey's HSD test. Tukey's HSD test was applied to find out that which two groups has significantly different mean scores from each other.

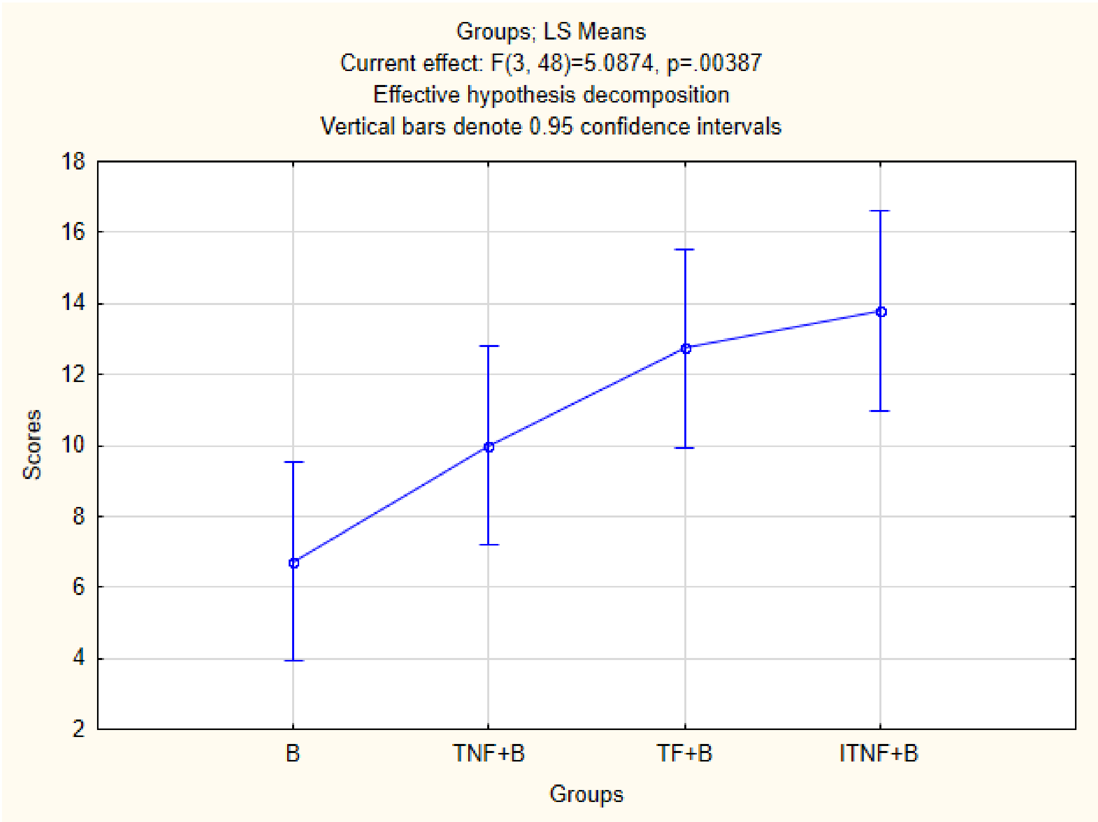

Figure 14 ANOVA comparison of early stage between B, TNF+B, TF+B and ITNF+B groups

Cell No.	Tukey HSD test; variable Scores (early.sta) Approximate Probabilities for Post Hoc Tests Error: Between MS = 25.529, df = 48.000 Groups	{1} 6.7308	{2} 10.000	{3} 12.731	{4} 13.808
1	B		0.361386	0.020080	0.004526
2	TNF+B	0.361386		0.519158	0.232937
3	TF+B	0.020080	0.519158		0.947946
4	ITNF+B	0.004526	0.232937	0.947946	

Figure 15 Post-hoc analysis of early stage ANOVA comparison

Cell No.	Groups; LS Means (early.sta) Current effect: F(3, 48)=5.0874, p=.00387 Effective hypothesis decomposition Groups	Scores Mean	Scores Std.Err.	Scores -95.00%	Scores +95.00%	N
1	B	6.73077	1.401341	3.91318	9.54835	13
2	TNF+B	10.00000	1.401341	7.18241	12.81759	13
3	TF+B	12.73077	1.401341	9.91318	15.54835	13
4	ITNF+B	13.80769	1.401341	10.99011	16.62528	13

Figure 16 Mean Scores of each group in early stage

6.2.1.1 Comparison of TNF+B and B

Tukey's test showed that there is no significant difference between scores of groups TNF+B (Mean Score=10) and B (Mean Score=6.73) as p=0.3613 (p>0.05).

6.2.1.2 Comparison of TF+B and B

Tukey's test showed that a significant difference exists between groups TF+B (Mean Score=12.73) and B (Mean Score=6.73) as p=0.02 (p<0.05).

6.2.1.3 Comparison of ITNF+B and B

Tukey's test showed that a significant difference exists between groups ITNF+B (Mean Score=13.81) and B (Mean Score=6.73) as p=0.0045 (p<0.05).

6.2.1.4 Comparison of TNF+B and TF+B

Tukey's test showed that there is no significant difference between groups TNF+B (Mean Score=10) and TF+B (Mean Score=12.73) as p=0.5191 (p>0.05).

6.2.1.5 Comparison of TNF+B and ITNF+B

Tukey's test showed that there is no significant difference between groups TNF+B (Mean Score=10) and ITNF+B (Mean Score=13.81) as p=0.2329 (p>0.05).

6.2.1.6 Comparison of TF+B and ITNF+B

Tukey's test showed that there is no significant difference between groups TF+B (Mean Score=12.73) and ITNF+B (Mean Score=13.81) as p=0.9479 (p>0.05).

6.2.1.7 Deduction

Therefore, it can be deduced that groups ITNF+B (Mean Score=13.81) and TF+B (Mean Score=12.73) that performed imagery of tapping task and tapping task prior to performing button task, have significantly higher scores inearly stages as compared to the group B (Mean Score=6.73) which only performed the button task.

The above results are also given below in the form of accuracy measure that gives a better visual representation. Early session accuracy scores of ITNF+B and TF+B are 46.02% and 42.43% whereas group B has an accuracy of 22.42%.

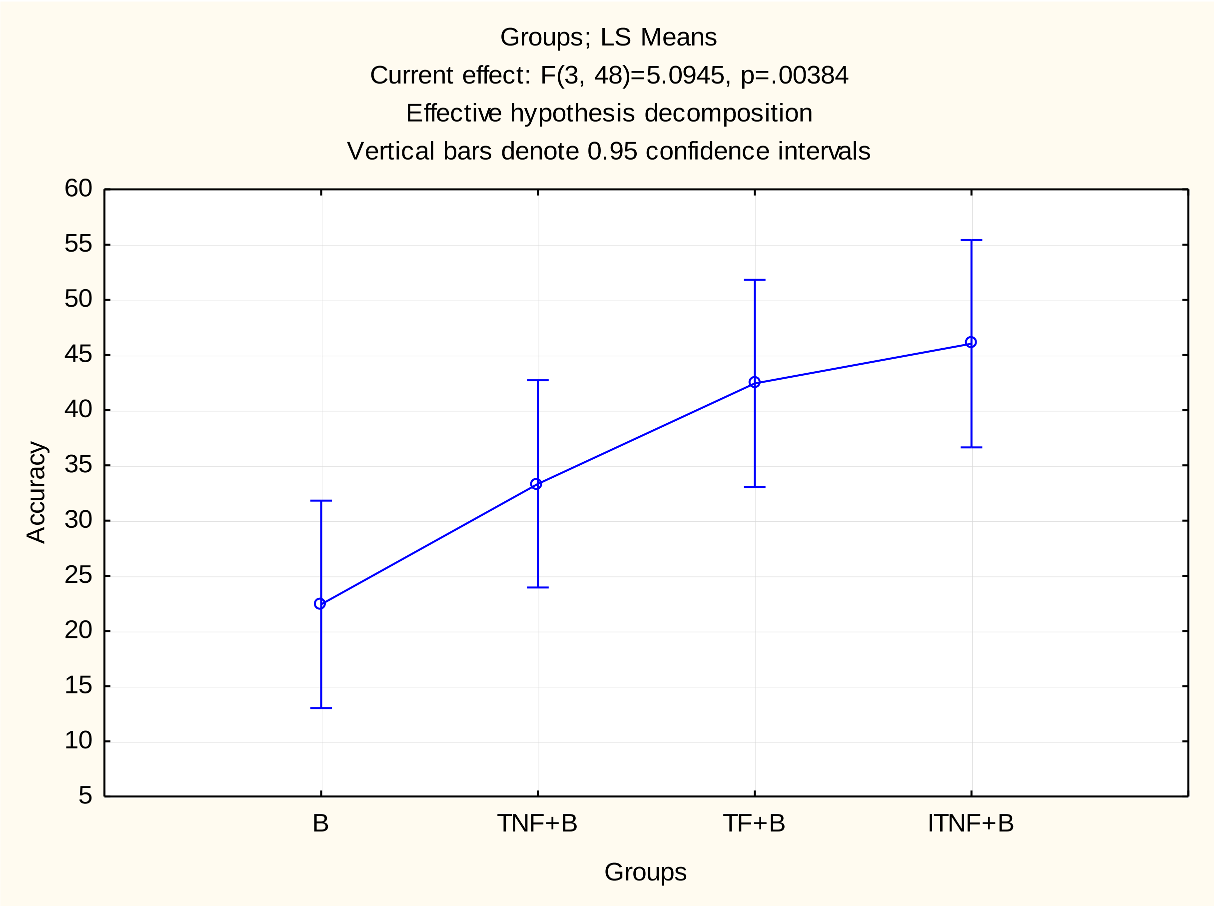

Figure 17 Accuracy representation of ANOVA comparison of early stage between B, TNF+B, TF+B and ITNF+B groups

Cell No.	Groups; LS Means (early.sta) Current effect: F(3, 48)=5.0945, p=.00384 Effective hypothesis decomposition Groups	Accuracy Mean	Accuracy Std.Err.	Accuracy -95.00%	Accuracy +95.00%	N
1	B	22.41615	4.670516	13.02545	31.80685	13
2	TNF+B	33.32692	4.670516	23.93622	42.71762	13
3	TF+B	42.43000	4.670516	33.03930	51.82070	13
4	ITNF+B	46.01923	4.670516	36.62853	55.40993	13

Figure 18 Mean accuracy scores of each group in early stage

6.2.2 Multi-group Comparison of Late Stage

One-way ANOVA on late stage sessions of groups B, TNF+B, TF+B and ITNF+B results in F(3,48)=7.2271 and p=0.00043 (p<0.05) which shows that a significant difference in scores exists between these groups. Since ANOVA cannot predict that which two groups differ from each other, so post-hoc analysis was performed using Tukey's HSD test. Tukey's HSD test was applied to find out that which two groups has significantly different mean scores from each other.

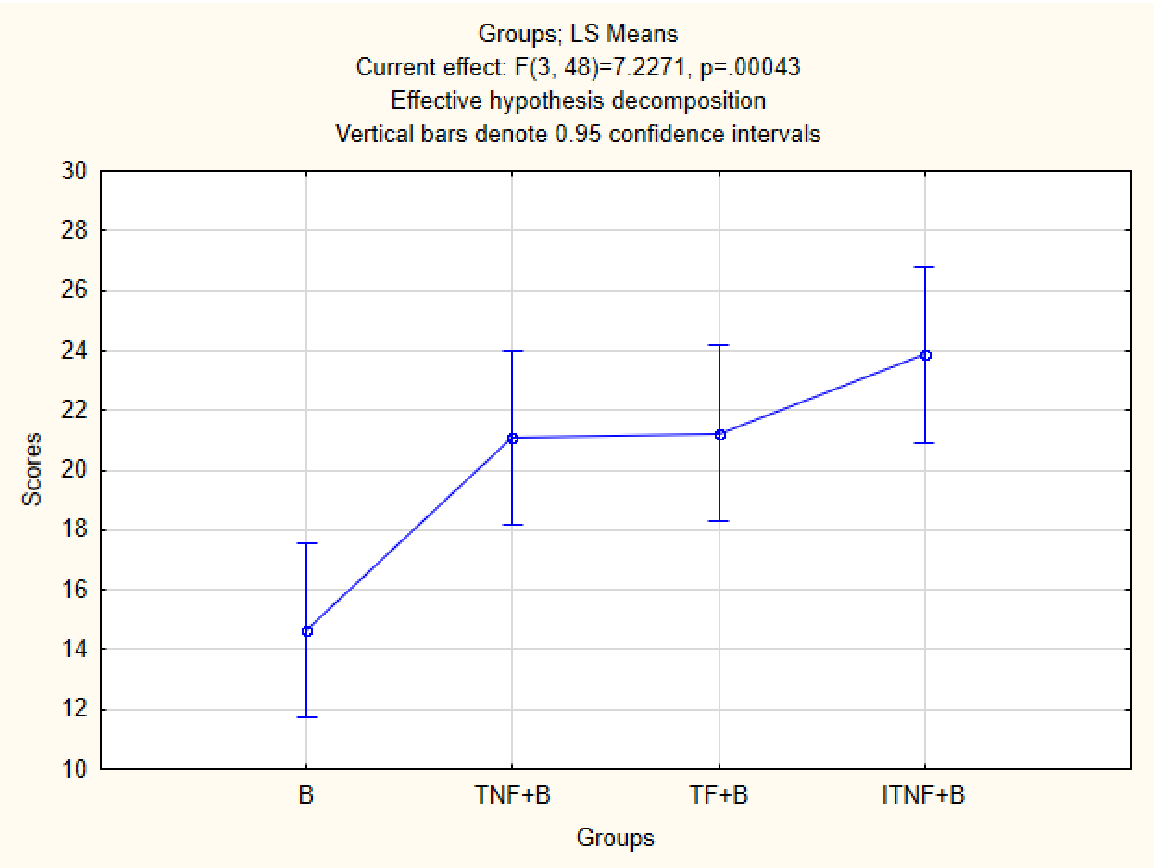

Figure 19ANOVA comparison of late stage between B, TNF+B, TF+B and ITNF+B groups

Cell No.	Tukey HSD test; variable Scores (late.sta) Approximate Probabilities for Post Hoc Tests Error: Between MS = 27.513, df = 48.000 Groups	{1} 14.654	{2} 21.077	{3} 21.231	{4} 23.846
1	B		0.015660	0.012805	0.000417
2	TNF+B	0.015660		0.999866	0.538881
3	TF+B	0.012805	0.999866		0.585486
4	ITNF+B	0.000417	0.538881	0.585486	

Figure 20Post-hoc analysis of late stage ANOVA comparison

Cell No.	Groups; LS Means (late.sta) Current effect: F(3, 48)=7.2271, p=.00043 Effective hypothesis decomposition Groups	Scores Mean	Scores Std.Err.	Scores -95.00%	Scores +95.00%	N
1	B	14.65385	1.454775	11.72882	17.57887	13
2	TNF+B	21.07692	1.454775	18.15190	24.00194	13
3	TF+B	21.23077	1.454775	18.30575	24.15579	13
4	ITNF+B	23.84615	1.454775	20.92113	26.77118	13

Figure 21Mean Scores of each group in early stage

6.2.2.1 Comparison of TNF+B and B

Tukey's test showed that a significant difference exists between scores of groups TNF+B (Mean Score=21.08) and B (Mean Score=14.65) as p=0.0156 ($p<0.05$).

6.2.2.2 Comparison of TF+B and B

Tukey's test showed that a significant difference exists between scores of groups TF+B (Mean Score=21.23) and B (Mean Score=14.65) as p=0.0128 ($p<0.05$).

6.2.2.3 Comparison of ITNF+B and B

Tukey's test showed that a significant difference exists between scores of groups ITNF+B (Mean Score=23.85) and B (Mean Score=14.65) as p=0.0004 ($p<0.05$).

6.2.2.4 Comparison of TNF+B and TF+B

Tukey's test showed that there is no significant difference between groups TNF+B (Mean Score=21.08) and TF+B (Mean Score=21.23) as p=0.9998 ($p>0.05$).

6.2.2.5 Comparison of TNF+B and ITNF+B

Tukey's test showed that there is no significant difference between groups TNF+B (Mean Score=21.08) and ITNF+B (Mean Score=23.85) as p=0.5388 ($p>0.05$).

6.2.2.6 Comparison of TF+B and ITNF+B

Tukey's test showed that there is no significant difference between groups TF+B (Mean Score=21.23) and ITNF+B (Mean Score=23.85) as p=0.5854 (p>0.05).

6.2.2.7 Deduction

Therefore, it can be deduced that groups ITNF+B (Mean Score=23.85), TF+B (Mean Score=21.23) and TNF+B (Mean Score=21.08)that performed any variation of practice tapping task prior to performing button task ends up with significantly higher scores inlate stage as compared to the group B (Mean Score=14.65) which only performed the button task.

The above results are also given below in the form of accuracy measure that gives a better visual representation. Late session accuracy scores of ITNF+B, TF+B and TNF+B are 79.47%, 70.77% and 70.24% respectively whereas group B has an accuracy of only 48.84%.

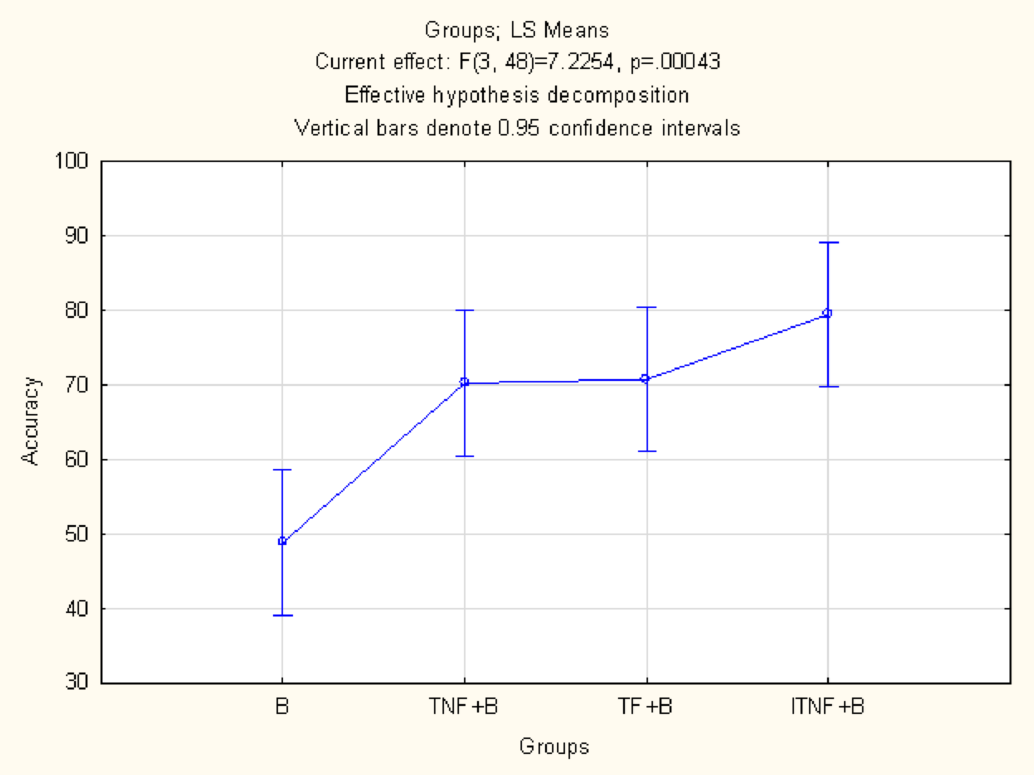

Figure 22Accuracy representation of ANOVA comparison of late stage between B, TNF+B, TF+B and ITNF+B groups

Cell No.	Groups; LS Means (late.sta) Current effect: F(3, 48)=7.2254, p=.00043 Effective hypothesis decomposition					
	Groups	Accuracy Mean	Accuracy Std.Err.	Accuracy -95.00%	Accuracy +95.00%	N
1	B	48.83769	4.849093	39.08794	58.58745	13
2	TNF+B	70.24231	4.849093	60.49255	79.99206	13
3	TF+B	70.76538	4.849093	61.01563	80.51514	13
4	ITNF+B	79.47231	4.849093	69.72255	89.22206	13

Figure 23Mean accuracy scores of each group in late stage

6.3 Relationship of individual Imagery Ability with Button Task Performance

As discussed previously in section 5.4 kinesthetic imagery ability scores of subjects were determined using KVIQ-10 questionnaire.

6.3.1 Correlation of Kinesthetic Imagery Ability with Button Task Performance Scores of Early Stage

The kinesthetic imagery ability scores were correlated with performance scores of button task in the early session of the group ITNF+B that gives a weak negative correlation with r = -0.2768. This means that participants with lower imagery scores performed relatively better from those who had higher imagery scores, however, the correlation here is not significant.

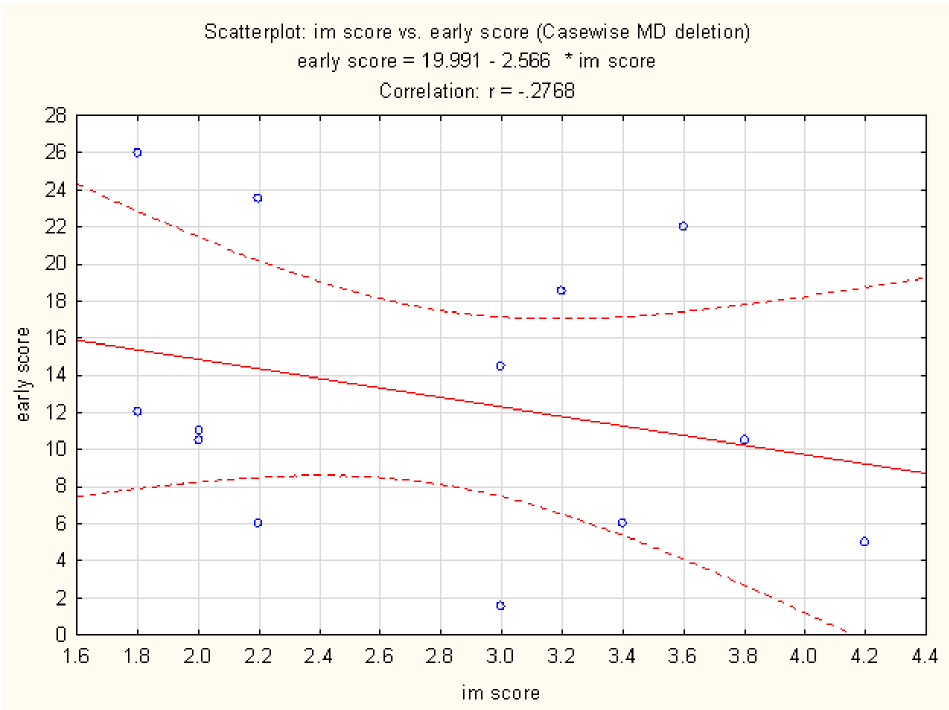

Figure 24 Correlation between imagery ability and early session performance scores of group ITNF+B

Var. X & Var. Y	Mean	Std.Dv.	r(X,Y)	r²	t	p	N
	Correlations (corr_imagery.sta) Marked correlations are significant at p < .05000 (Casewise deletion of missing data)						
im score	2.78462	0.826485					
early score	12.84615	7.660463	-0.276811	0.076625	-0.955413	0.359894	13

Figure 25 Detailed Correlation Statistics of imagery ability and early session performance scores of ITNF+B

6.3.2 Correlation of Kinesthetic Imagery Ability with Button Task Performance Scores of Late Stage

The kinesthetic imagery ability scores were correlated with performance scores of button task in the late session of the group ITNF+B that gives a strong negative correlation with r = -0.6889. This means that participants with lower imagery scores performed relatively better from those who had higher imagery scores andtheir correlation is alsosignificant.

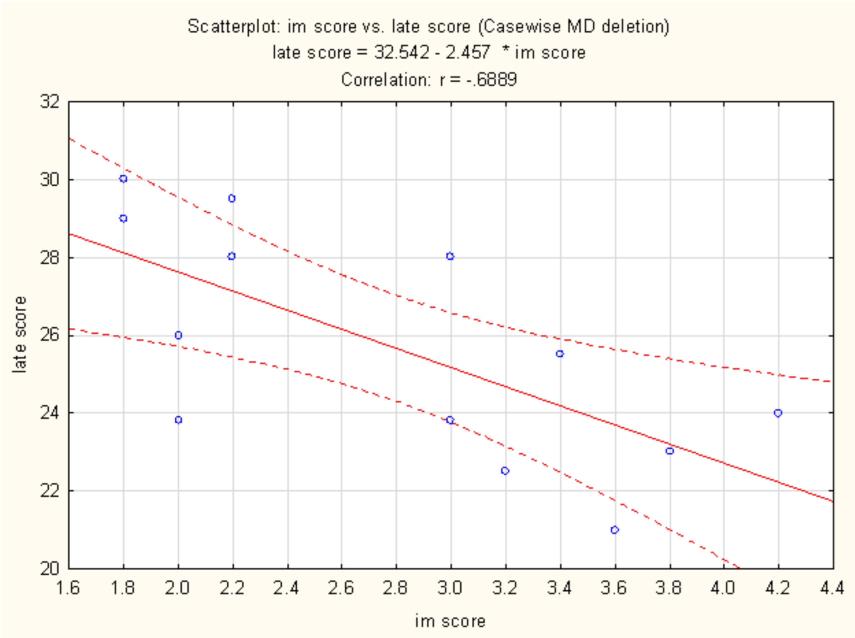

Figure 26Correlation between imagery ability and late session performance scores of group ITNF+B

Var. X & Var. Y	Mean	Std.Dv.	r(X,Y)	r²	t	p	N
	Correlations (corr_imagery.sta) Marked correlations are significant at p < .05000 (Casewise deletion of missing data)						
im score	2.78462	0.826485					
late score	25.70000	2.947598	-0.688930	0.474625	-3.15237	0.009203	13

Figure 27Detailed Correlation Statistics of imagery ability and late session performance scores of ITNF+B

PART IV

DISCUSSION

&

CONCLUSION

7 Discussion

7.1 Summary

The first objective of the study was to induce plasticity through motor imagery of a bimanual finger-tapping task and to determine its effects on performance of a subsequent bimanual button task. Second objective was to determine that if individual motor imagery scores has any impact on performance scores of button task after motor imagery of bimanual finger tapping task.

Group ITNF+B, which performed motor imagery of tapping task and button task, had 46.02% button task performance score accuracy in early session and TF+B had an accuracy of 42.43%, whereas group B had an accuracy of 22.42%. Early session performance scores show maximum improvement because of motor imagery as compared to all other groups. Moreover, late session accuracy scores of ITNF+B (motor imagery of tapping task and button task), TF+B (motor execution of tapping task with feedback and button task) and TNF+B (motor execution of tapping task without feedback and button task) are 79.47%, 70.77% and 70.24% respectively whereas group B has an accuracy of only 48.84%. So motor imagery group was also able to reach maximum scores with an accuracy rate of 79.47% in late stages.

Correlation of individual motor imagery ability with performance scores of button task resulted in negative correlation in both early and later stages of learning. Correlation observed was weakly negative with $r = -0.2768$, whereas a significant negative correlation was observed in late stages of learning with $r = -0.6889$. This shows that subjects with strong imagery ability performed poor when practice and performance tasks were different as compared to subjects with low imagery ability.

7.2 Comparison

Motor learning of a task is not just acquiring a new skill but it involves alteration of existing habits and behaviors[78]. In addition, motor learning of a behavior impacts goes both ways. Previous and newly acquired behaviors, both are effected in some way however, pre-existing behaviors have a more effect on new skill [78]. The results obtained support these statements as practice of tapping task with motor imagery enhanced the actual performance of button task.

Previous studies have also put more emphasis on physical practice as compared to mental practice and it has been suggested that actual practice is better whenever it is possibleas compared to mental practice [79, 80].However, performance accuracy of imagery group in our study is highest among all groups in both early and late learning stages. The difference is not significant from actual practice groups;however, the results are contradictory to what has been suggested by previous studies.

Subjects with strong imagery ability performed poor when practice and performance tasks were different as compared to subjects with low imagery ability. This shows that high imagery scorers have disruption in task imagination with the presence of a goal. Therefore, it can be deduced that high imagery scorers are likely to be disrupted in the actual task performance after imagery practice of different task. This has not been yet tested in terms of different motor task after imagery practice of a task; however, a study employing two different motor imagery task supports our results[81].

7.3 Limitations

Sample size was 13 in our study. Increasing the sample size will result in better representation of obtained results. Subjects performed only kinesthetic imagery and only kinesthetic imagery ability of subjects was measured. Including visual imagery will give better insight to the results. One major limitation is that we cannot measure or guess if the subject is actually imagining the task they are supposed to do. Questionnaires are used to give subjects better understanding of how to perform the imagery.

8 Conclusion

This study suggest that previously learned behaviors using motor imagery can facilitate the learning of new motor behaviors. In fact, imagery practice of a motor behavior yields better results in learning of new behavior as compared to actual practice.

In addition, imagery score of an individual, after practice of one motor behavior, also modulates the learning of a new behavior.

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