Positive Impact of Practice Driven Plasticity on a Subsequent Motor Task

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Declaration

I hereby certify that this research study is entirely my own work and has been submitted for the partial fulfillment of requirements for the degree of Master of Science in Biomedical Engineering. I hereby declare that I have exercised reasonable care to ensure that the work is original, and does not to the best of knowledge breach any law of copyright, and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

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“After you make a fool of yourself few hundred times, you learn what works”.

(Gwen Stefani)

To

“Ammi, Abbu ji”

&

“Farooq Zafar Rajpoot”

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List of Abbreviations

LTP	Long-term potentiation
T/F	Tapping task with feedback
T/NF	Tapping task without feedback
B	Bimanual button pressing task
T/F+B	Tapping task with feedback and Bimanual button pressing task
T/NF+B	Tapping task without feedback and Bimanual button pressing task
PTB-3	Psychtoolbox-3
PPC	Posterior parietal cortex
SM1	Sensorimotor cortex
IFG	Inferior frontal gyrus
IOI	Inter onset interval
ERP	Event-related potential
ERS	Event-related synchronization
ERD	Event-related desynchronization
SMR	Sensorimotor rhythms
PET	Positron emission tomography
fMRI	Functional magnetic resonance imaging
EEG	Electroencephalography

BOLD	Blood oxygen level-dependent
DLPFC	Dorsolateral prefrontal cortex
SMA	Supplementary motor area
SRTT	Serial reaction time task
LTD	Long-term depression

ABSTRACT

Background: Motor skills are gained through practice reflecting neuroplasticity. Interest in inducing plasticity employing conventional (Transcranial magnetic stimulation (TMS) etc.,) and non-conventional methods (Bimanual finger tapping, locomotor adaptation, sequence learning etc.,) for rehabilitation procedures has increased.

Objective: The objectives of the study were; to induce plasticity through bimanual finger tapping task over training sessions; and to determine to what extent this practice driven plasticity effects the performance and learning of subsequent motor task.

Method: Behavioral data from 39 healthy subjects was recorded. They were randomly divided into three equal groups. First group performed bimanual finger tapping task according to 2:1 ratio mode with feedback and bimanual button pressing task (T/F+B). Second group performed bimanual finger tapping task according to 2:1 ratio mode without feedback and bimanual button pressing task (T/NF+B). Third group only performed bimanual button pressing task (B). Task accuracy was determined for performance evaluation.

Main Results: Accuracy for T/F was F (1,24) = 45.551, $p<0.05$, for T/NF was F (1,24) = 26.382, p=.00003 respectively and that for (B) was F (1,24) = 8.6817, p=.00704. At early stage, subjects performed T/F+B were better than those performed T/NF+B and B but at late stage there was no significant difference between T/F+B and T/NF+B. However, both T/F+B and T/NF+B performed better than B.

Significance: The results show that finger tapping task has the potential to induce plasticity in human brain due to synchronization of hemispheres. This practice driven plasticity can be used to enhance the learning of a new motor task. Results reveal that the induced plasticity positively influences the learning of a subsequent motor task.

Keywords: Neuroplasticity, motor learning, bimanual finger tapping, intrinsic behavior, feedback, Pyschtoolbox-3, MATLAB, rehabilitation.

PART I

INTRODUCTION & LITERATURE REVIEW

The central nervous system has an extensive range of tasks: acquiring sensory input, gathering memories, motor coordination, posture maintenance, consciousness and developed thought production. The nervous system achieves this miscellany of functions with one fundamental element: it can alter and acclimatize. Due to which, features can be attuned to the current task along with acquiring of new properties.

1 Plasticity

Neuroplasticity or plasticity is the ability of nervous system (or the neurons) to reorganize their functional and anatomical connectivity along with the properties as a reaction to environmental input. This definition incorporates molecular, structural, physiological and functional changes but the most interesting form is the one that obeys Hebbian principles as first described by Daniel Hebb:

"When an axon of cell A is near enough to excite cell B and repeatedly or persistently takes part in firing it, some growth process or metabolic change takes place in one or both cells such that A's efficiency, as one of the cells firing B, is increased". (Hebb 1949)

This depiction has often been abridged as "neurons that fire together, wire together". Hebbian rules develop the mathematical foundation of neural network models and offer a principle that conducts neuroplasticity, letting synapses to preserve a memory of preceding action.The first evidence for the molecular basis of a nervous system showing neuroplasticity and adaption of its motor behavior was found in the invertebrate *Aplysia californic*. Changes in synaptic properties were appeared to happen after the Aplysia californica had obtained a memory
(Frazier, Kandel et al. 1967; Castellucci, Pinsker et al. 1970; Kupfermann, Castellucci et al. 1970; Pinsker, Hening et al. 1973).

Long-term potentiation (LTP) is a sort of activity-dependent plasticity which results in a pertinacious augmentation of synaptic transmission. Since the discovery of LTP in the early 1970s, (Bliss and Lømo 1973) it has been a foundation of great interest to neuroscientists because it fulfils conditions for a synaptic memory mechanism suggested by Donald Hebb in his persuasive book 'The Organization of Behavior' (Hebb 1949). Particularly, LTP is long-term and input-particular (modifications can be made at one set of synapses on a cell deprived of disturbing other synapses). The opposite process of long-term depression (LTD), in which the effectiveness of synaptic transmission is abridged, shares these features and has also gained much awareness (Ito and Kano 1982; Dudek and Bear 1992) . Most neuroscientists believe that LTP and LTD are genuine synaptic processes and basis for learning and memory but it has not yet been decided (Sanes and Lichtman 1999; Martin, Grimwood et al. 2000). On the other hand, at the molecular level, it is very unambiguous that LTP/LTD and numerous forms of memory depend on alike molecular mechanisms. Moreover, it has been established that LTP and LTD like alterations in synaptic strength happen as a memory is made at several sets of synapses in the brain, and that these alterations can obstruct the artificial generation of LTP and can be obstructed by the earlier induction of LTP (Rioult-Pedotti, Friedman et al. 2000; Sacchetti, Lorenzini et al. 2001; Doyère, Dębiec et al. 2007; Tye, Stuber et al. 2008).

2 Motor Learning

Conventional categorizations of learning and memory discriminate among learning of implicit and explicit memories. Motor learning fits in the class of implicit learning where intricate information is grasped with absence of the capability to deliver conscious verbal remembrance of what has been learned.

Motor learning as described by Krakauer:

"Motor learning does not need to be rigidly defined in order to be effectively studied. Instead it is better thought of as a fuzzy category that includes skill acquisition, motor adaptation, such as prism adaptation, and decision making, that is, the ability to select the correct movement in the proper context. A motor skill is the ability to plan and execute a movement goal." (Krakauer, 2006)

Instead of actual definitions Shadmehr & Wise have chosen mechanistic explanations:

"Motor learning takes many forms, including:

(1) learning over generations that becomes encoded in the genome, is epigenetically expressed as instincts and reflexes, and contributes to learned (conditioned) reflexes;

(2) learning new skills to augment your inherited motor repertoire, and adapting those skills to maintain performance at a given level; and

(3) learning what movements to make and when to make them." (Shadmehr & Wise, 2005)

However, it is suitable to utilize broadest description of motor learning: a long-lasting modification in motor performance developed by precursory experience. This comprises the subsequent definition of learning:

"Learning involves changes in behavior that arise from interaction with the environment and is distinct from maturation, which involves changes that occur independent of such interaction"(Wolpert, Ghahramani et al. 2001).

The key element from the above descriptions of motor learning comprises a change in motor performance. Outcome (motor performance) is dependent on goal and can be deliberated in a number of ways. The optimization of outcome can be both goal oriented and task oriented.

2.1 Motor Learning Paradigms

Following are some typical types of motor learning paradigms:

2.1.1 Sequence Learning

Sequence or procedural learning was first developed as the serial reaction time task (SRTT) (Nissen and Bullemer 1987). Subjects performed reiterating sequences of button presses and the reaction time turned out to be gradually faster. After that the reaction time would be slower for a different sequence of pressing buttons. Consequently, the difference between a random sequence and repeating one measures a rate of learning. Employing mixed or probabilistic series of pressing buttons, rate of learning in non-dominant hand, complex movements and non-spatial cues deal with deficiencies associated with this task. Brain networks identified by functional imaging studies linked to this task are: dorsolateral prefrontal cortex, supplementary motor area and cerebellum. Ecological validity and lack of generality for this kind of learning are some of the deficiencies with this paradigm. There are some deficiencies with this paradigm, including the lack of generalization of this learning and the ecological validity when used as a clinical test (Muslimović, Post et al. 2007). Nevertheless, it is well-known and extensively used paradigms of motor learning in humans.

2.1.2 Ballistic Motor Learning

The ballistic motor learning task was developed by (Muellbacher, Ziemann et al. 2001). The task revealed that peak thumb acceleration was gradually increased by voluntary recurrent thumb abduction. The plasticity needed for improving performance in this task is confined to the primary motor cortex (Muellbacher, Ziemann et al. 2002) and (Classen, Liepert et al. 1998) documented changes in motor representation. Moreover, repetitive use only is linked with alterations in cortical excitability (Muellbacher, Ziemann et al. 2001; Kaelin-Lang, Sawaki et al. 2005) while functional Activation patterns on fMRI was documented by (Karni, Meyer et al. 1998). Some have indicated this as ‘use’-dependent effect or ‘practice’ to some extent than learning as it is naturally challenging to perceive the ‘learning’ behind this method. On the other hand, from a motor system’s perception, the motor system definitely has to attain new information causing a long-lasting performance improvement with respect to time, through 'learning' the amalgamation of antagonist and agonist motor units necessary to yield the optimum thumb peak acceleration. This proposes that this is a very rudimentary form of motor learning.

2.1.3 Visuomotor transformation

Visuomotor transformation is an extensive class of tasks combining visual and proprioceptive sensory learning with motor learning. It comprises execution of motor task with transformation of the visual sensory feedback such as rotations, mirroring, displacements, depth distortion and inversions. Standard tasks include rotor pursuit (Ammons 1951; Ammons, Farr et al. 1958) and mirror drawing (Corkin 1968). Mirror drawing is self-evident task but could be strenuous to quantify while rotor pursuit is a kind of continuous motor task in which subjects have to trace a predictable moving target (rotor) with the hand (Ammons 1951). Its modern versions employ styluses along with computer screens to give visual feedback. In this case visual feedback manipulation is not dependent on proprioceptive feedback. Brain areas involved in this task are supplementary motor area (SMA), dorsolateral prefrontal cortex (DLPFC), pre motor cortex, inferior frontal and parietal cortex, basal ganglia, primary motor cortex and cerebellum as well (Halsband and Lange 2006). The diversity of sensory and visual feedback employed makes comparison of tasks difficult within this classification.

2.1.4 Force Field Adaptation

This task involves utilizing a robotic arm in a reaching movement but the robotic arm provides resistance, therefore mimicking a force field (Shadmehr and Mussa-Ivaldi 1994). The dynamics of reaching movements are affected by force field. In the beginning, trajectories of movement are utterly distorted but along with repetition, trajectories mimic normal one in free space. This experimental pattern recommends a system through which the nervous system progressively forms an inner model of force field and acclimate motor behavior '*using an intrinsic coordinate system of the sensors and actuators*' (Shadmehr and Mussa-Ivaldi 1994; Conditt, Gandolfo et al. 1997). This paradigm is also linked to visuomotor transformations because it involves the mapping of sensory input to motor commands along with an improved model of enactment at baseline. Functional imaging reveals that after practicing for hours, improvement is retained along with alteration of initiation pattern with more cerebellar, premotor and parietal cortices being engaged (Shadmehr and Holcomb 1997; Nezafat, Shadmehr et al. 2001). Interventions have proposed that this kind of learning does not depend on the primary motor cortex (Baraduc, Lang et al. 2004). Force field adaptation has been broadly studied particularly in robotics and engineering. Based on experimental data intricate computational models have been attained from this task (Shadmehr and Wise 2005).

2.1.5 Locomotor Adaptation

Limited number of studies focuses, whether motor learning paradigms in trunk or lower limbs works on the same principle as for upper limbs. This is due to the fact that majority of motor learning models emphasis on hands and upper limbs. In order to correct this prejudice, a new motor learning model is 'split-belt treadmill walking'. This task requires subjects to learn walking on a treadmill in such a way that each lower limb walks on a separate belt with a different rate (Morton and Bastian 2006). This paradigm showed that different functional networks governs different walking criterion and it comprises adaptation of the central pattern generators in the spinal cord along with their descending control (Choi and Bastian 2007). Up till now, a small number of research groups have employed this experimental paradigm.

2.1.6 Classical Conditioning

A Russian physician, Ivan Pavlov, although pondering salivary and gastric functions of dogs unintentionally discovered a form of associative learning called Pavlovian or classical conditioning. He also won the Nobel Prize in Physiology and Medicine (Pavlov 1927). In this study, Pavlov explained pairing of a sensory conditioned stimulus with unconditioned one that produces a spontaneous unconditioned motor response, such that after consecutive pairings the conditioned stimulus incites the spontaneous conditioned motor response. Pavlov also defined the concept of obsolescence where the connotation between the conditioned stimulus and unconditioned response vanishes if the conditioned stimulus is given recurrently in the absence of the unconditioned stimulus. This model has been evolved over the 20th century and eye blink classical conditioning is the standard modern paradigm, well-explained in mammals (as well as humans) (Gormezano and Moore 1966).

Repetitive brief auditory tone (conditioned stimulus) played for a small delay earlier than unconditioned stimulus; ultimately yields conditioned responses: flickers taking place earlier or not in the presence of unconditioned stimulus. Brain areas involved in this paradigm are inferior olives, cerebellar nuclei, pontine structures and probably cerebellar cortex Detailed knowledge is known about the circuits, brain regions and molecular processes involved in this paradigm with central roles played by pontine structures, the inferior olives, the cerebellar nuclei (and possibly the cerebellar cortex) (Gerwig, Hajjar et al. 2005; Gerwig, Kolb et al. 2007; Wada, Kishimoto et al. 2007). This paradigm also involves detailed knowledge about brain regions, molecular processes and circuits. Decerebrate animals do not have problems to get this classical conditioning (Jirenhed, Bengtsson et al. 2007). Classical conditioning is deliberated as ‘primitive’ and somewhat separated in cerebellar structures and brainstem. These paradigms are also employed to study some other kinds of memory and learning such as fear conditioning.

2.1.7 Aimed Rapid Movements

A psychomotor principle first defined by Paul Fitts known as Fitts Law governs all aimed rapid movements (Fitts 1954). This law describes that there is an inverse relationship between accuracy and speed when pointing promptly at a target. Mathematical expression of Fitts Law is stated as:

$$MT = a + bID$$

$$ID = log_2(2A/W)$$

Where MT is movement time, ID is index of difficulty, A is the distance from starting point to center of target, W is the width of the target, *a* and *b* are coefficients.

Fitts' Law therefore also shows a speed-accuracy trade-off when carrying out prompt pointing movements. The slope coefficient, b, is of specific significance to motor learning as it generally deciphers into the amount that action time accelerates for a given unit of difficult, and recurrent practice is connected with a decrease of this coefficient (Schmidt and Lee 1988). Some have suggested that b (change in slope) reveals skill acquisition (Reis, Robertson et al. 2008). Some other older studies incline to have a greater slope (Welford, Norris et al. 1969; Goggin and Meeuwsen 1992; Welsh, Higgins et al. 2007) but it is still vague if higher slope is because of peripheral mechanical factors or central nervous system. Some intrinsic limitations include peripheral mechanical factors affecting the slope and its use in disease models. On the other hand some rapid aimed movement tasks amalgamate features of visuomotor transformations as well such as inclined increase of force due to visual feedback evidently consist of visuomotor transformation incorporating speed-accuracy trade-off when precision is necessary (Muellbacher, Ziemann et al. 2001; Ward, Brown et al. 2003).

2.1.8 Finger Tapping Tasks

Finger-tapping tasks are generally employed to study the human motor system having the benefit of being easy enough to utilize in the study of normal control subjects as well as with neuro-pathologies influencing the motor system. Finger tapping tasks are sufficiently flexible to incorporate several amendments. These tasks can diverse among studies due to presence or absence of a pacing stimulus and the relative complexity in task. In order to ensure the uniformity in performance of finger tapping task at a preset rate pacing stimuli is used. Pacing stimuli is sort of regularly paced, recurrent visual or auditory cue produced by an isochronous metronome (Colebatch, Deiber et al. 1991; Sadato, Campbell et al. 1996; Catalan, Honda et al. 1998) or blinking some sort of light (Jäncke, Loose et al. 2000; Indovina and Sanes 2001). Tasks performed in presence of pacing stimuli are generally mentioned as externally guided/ generated and those performed in absence of pacing stimulus are referred as self-paced or internally guided/

generated. Pacing stimuli often combine complex finger tapping like bimanual tasks (tapping of fingers of both hands) or sequential multi finger tapping tasks.

2.2 Adaptation versus Skill Learning

(Shadmehr and Wise 2005) tried to sub-categorize motor learning paradigms and have delivered a significant difference between learning and adapting of a new motor skill: (1) Learning a motor skill is an extension of motor repository or acquirement of a new motor task with generality to other motor programs; (2) Motor adaptation is the retuning of an existing motor task in changed situations to retain performance.

From the above distinction it is clear that locomotor adaptation and force-filed adaptation are paradigms that test motor adaptations while classical conditioning and sequence learning are testing learning of a new motor skill. One the other hand it is also more challenging to categorize some paradigms like ballistic motor learning and visuomotor transformations because both resembles adaptation. In Visuomotor transformations being capable to ‘mirror draw’ is evidently a novel motor skill and a new motor force vector is being learnt in Ballistic motor learning. The diverse models of motor learning might recommend that there are more dissimilarities than resemblances among the learning of separate motor tasks. On the other hand, mathematical relationships among movement features like kinematics, accuracy and speed, advise that there are fundamental principles in motor learning and behavior and these resemblances could reveal vital features of the brain structure and network function. Some of these vital features are expected to rely on molecular principles of neuroplasticity whereas others probably reflecting dependency among different brain networks. Motor learning appears to be an evolving thing due to interaction of different brain regions rather than separate neuroplasticity in one brain region. This neuroplasticity permits interaction among multiple brain regions to be dynamic along with the possibility to set limits and rules for motor learning.

3 Relationship between Plasticity and Motor Learning

It is generally assumed that there is a relation among neuroplasticity and motor learning. The evidence of connection between representations of human neuroplasticity and human motor learning is also inadequate. Variations in physiological factors of excitability are related with ballistic motor learning, and this is named practice-dependent plasticity (Classen, Liepert et al. 1998; Muellbacher, Ziemann et al. 2001; Muellbacher, Ziemann et al. 2002). These changes are believed to be because of variations in synaptic effectiveness possibly encompassing LTP (Boroojerdi, Battaglia et al. 2001; Ziemann, Muellbacher et al. 2001), similar to animal models of practice-dependent plasticity (Rioult-Pedotti, Friedman et al. 1998; Rioult-Pedotti, Friedman et al. 2000; Sanes and Donoghue 2000). These variations are also goes along with a rise in functional MRI (fMRI) blood oxygen level-dependent (BOLD) signal revealing augmented neural activity (Lotze, Braun et al. 2003). (Ziemann 2004) have studied how diverse models work together with each other and have presented that preceding ballistic motor learning relates with succeeding artificial incitation of plasticity by rTMS. This recommends that rTMS induced plasticity and ballistic motor learning is possibly connected. Anodal TDCS could augment sequence learning (Nitsche, Liebetanz et al. 2003) but less successful among other paradigms (Agostino, Iezzi et al. 2007). Efficacy in motor learning probably requires encrypting of useful information into numerous brain networks whereas neuroplasticity alone is improbable to encode. This study reveals motor practice changing MEPs as well as sensorimotor organization, although paired-associative stimulation only influences MEPs demonstrating need for multiple brain networks (Rosenkranz and Rothwell 2006). Artificially induced plasticity in primary motor cortex yields indirect behavioral changes whereas motor learning produces more evident behavioral changes (Gerloff, Corwell et al. 1998; Muellbacher, Ziemann et al. 2000; Baraduc, Lang et al. 2004). Due to range of available motor learning paradigms, its relationship with neuroplasticity has become intricate. Diverse paradigms depend on separate systems thus providing distinct contributions.

4 Electroencephalography (EEG)

EEG is a popular technique to record electrical activity (acquire brain signals) in a non-invasive way by placing electrodes on a scalp, reflecting a preview of neural activity from the cortex. This makes EEG an effective means to study the relations between brain areas and different cortical networks. EEG records neural activity in real time and offers tremendous temporal resolution in the range of milliseconds, a big benefit over other present neuroimaging techniques such as functional magnetic resonance imaging (fMRI) or positron emission tomography (PET).

In scalp-recorded EEG, brain activity is revealed in a range of oscillations/rhythms. Each rhythm is discriminated by means of its frequency range, correlations with continuing brain activity scalp location and behavioral state (Niedermeyer and da Silva 2005). Although these rhythms are usually thought to basically reveal brain activity, it is probable that they play functional parts such as synchronizing cortical regions (Singer 1999; Fries, Nikolić et al. 2007; Montgomery and Buzsáki 2007). EEG recorded on primary sensorimotor cortex generally shows mu-rhythm (8-12 Hz) and beta rhythm (18-26 Hz) in relaxed awake persons (Kozelka and Pedley 1990; Fisch 1999; Niedermeyer and da Silva 2005). Thalamocortical circuits produce these sensorimotor rhythms (SMRs) (da Silva 1991; Niedermeyer and da Silva 2005). SMR activity encompasses a range of diverse rhythms that are discriminated from each other by frequency, relationship to simultaneous sensory input or motor outcome and location. Some beta rhythms are distinguishable from mu rhythms by means of topography and timing whereas others are harmonics of mu rhythms and consequently are independent EEG features (Pfurtscheller and Lopes da Silva 1999; McFarland, Miner et al. 2000). Movement or planning to move is generally followed by SMR decrease, particularly prior to the movement. This decrease has been categorized “event-related desynchronization” or ERD. It’s contrasting, rhythm increase, or “event-related synchronization” (ERS) occurs movement afterwards and with relaxation (Pfurtscheller and Lopes da Silva 1999).

5 Phase synchronization in the brain

Neurons are interconnected to a very large extent in the human brain. So, one can perceive the brain as a vast network comprising of millions of sub-networks varying from micro to macro level connections (Varela, Lachaux et al. 2001). It is generally believed that neural networks store information and intricate communication among neurons of similar and separate networks/ assemblies arouse human behavior (Fuster 1997; Varela, Lachaux et al. 2001). As previously stated, the EEG can only record neural activity if there is simultaneous/synchronized dendritic activity in a huge network of neurons, or in presence of very huge synchrony in the cortex below the electrode. Considering network properties or synchrony of cells at micro-level is not possible with scalp EEG due to its low spatial resolution. On the other hand, only inferences regarding synchronicity can be made on a large scale with EEG. Large scale will refer to activities involving distances among cortical lobes and between hemispheres.

This section will briefly focus on three different types of phase synchronization:

(i) phase coherence, (ii) phase coupling among frequencies, and (iii) phase-locking in reaction to beginning of sensory stimuli.

When similar brain activity is shown by two cortical areas and this activity is also related to on another in a fixed way, one can infer the functional connection of these two brain areas as they perform similar work at the same time.

5.1 Phase Coherence

Phase coherence is a measure of quantifying the resemblance between two signals from the brain. Therefore, if the phase angles of an oscillation reveal similar lag in each single trial recorded at EEG-electrodes A and B, the phase coherence (similarity) will be very high for these two locations. In other words, one can conclude that these two sites are somewhat functionally related and incorporated in task-relevant activities. Coherence among EEG electrode locations has been employed as measure for synchronous co-activation (Nunez, Srinivasan et al. 1997; Rappelsberger 1998; Nunez, Silberstein et al. 1999). In cognitive neuroscience phase coupling over distance has been implemented in research regarding visual perception, motor functions, attention, multisensory integration, and memory (Klopp, Marinkovic et al. 2000; Mima, Oluwatimilehin et al. 2001; Gross, Schmitz et al. 2004; Sauseng, Klimesch et al. 2004; Gomarus, Althaus et al. 2006).

5.2 Phase coupling over different frequencies

A different type of EEG synchronization is phase coupling over different frequencies. One can suppose that networks of different size because of different resonance frequencies oscillate at different frequencies. Therefore, in order to exchange information there should be some synchronization among two underlying network oscillations having different frequencies. To calculate this, techniques such as bi-coherence or cross-frequency phase synchronization have been evolved (Schack and Klimesch 2002; Palva, Palva et al. 2005; Schack and Weiss 2005). High cross-frequency phase synchronization should be obtained in EEG for two oscillations with different frequency irrespective of absolute instantaneous phase angles because their lag at a fixed point is always constant.

5.3 Phase-locking to onset of an external stimulus

A third type is phase-locking to onset of an external stimulus. The basic idea behind phase-locking is: an event-related potential (ERP) is produced after a sensory stimulus presented to the brain. Phase resetting of brain oscillations generated these ERPs (Sayers, Beagley et al. 1974; Başar 2012). This means that ongoing phase of a specific frequency is reset in reaction to an external stimulus in each single trial. The activity before the reset should approach zero when the single trials are averaged. While an ERP (brain response) should be the result. Therefore, phase-locking to stimulus onset point towards the association of certain frequencies in the strict timing of cognitive task linked to stimulus processing in order to create careful time windows and a temporal order for processing information (Klimesch, Hanslmayr et al. 2006). Brain synchronization phenomena replicate highly particular neural activity that delivers information regarding diverse cognitive functions which cannot be acquired from other means and brain activation evaluation.

Above mentioned types reveals extremely specific functions and produces essential information that is not confined in any other quantification of brain activity. As deliberated above, high temporal resolution is the benefit of phase measures in the human EEG. Phase synchronization appears more noticeable to measure neural communication on diverse spatial scales as compared to any other non-invasive brain activation evaluations. Due to poor temporal resolution correlation approaches in fMRI are less feasible for brain connectivity analysis. An extensive review paper showed that Phase synchronization in EEG carries vital information for deducing neuronal and cognitive processes (Sauseng and Klimesch 2008). It has been suggested that in EEG phase is more meaningful and instructive because many specific brain processes are controlled by phase of oscillation as compared to other parameters like amplitude which reflects general brain activation.

6 Tapping studies with an external stimulus

Finger tapping tasks synchronized with an external stimulus (normally computer-controlled) is a common paradigm due to its simplicity, flexibility and long history. To conduct tapping studies many researchers have equipment, made special software for experiments and data analysis (Finney 2001; Finney 2001; Elliott, Welchman et al. 2009; Kim, Kaneshiro et al. 2012). Synchronizing a movement with a sensory stimulus, like tapping in response to beep seems to be a simple task demanding small cognitive effort. On the other hand, it involves a complex distributed brain functions and neural connections whose tasks vary from simple timing processes to sensorimotor connection.

6.1 Auditory versus visual rhythms

Irrespective of the musical training, the irregularity of taps in synchronization with visual metronomes is usually greater as compared with auditory metronomes (Repp 2005). With inter onset interval (IOI) of 750 ms variability was somewhat larger with visual stimuli as compared to auditory one (Sugano, Keetels et al. 2012). When IOIs are less than 500 ms it is difficult to synchronize with fixed visual metronomes (Repp 2003). When subjects synchronize their task with a series of visual flashes followed by a sequence of auditory distractors, their taps deviate towards the distractor tones. On the other hand, visual distractors barely influence synchronization with auditory targets (Repp 2005).

6.2 Neural connections of covert synchronization

6.2.1 Timing Process

One basic requirement of movement synchronization is the capability to time the sensory input, like handling the time intervals among consecutive visual or auditory trials. It has been suggested that time perception involves two systems working diversely, linking distinct cortical–subcortical networks. “Automatic timing” of intervals is frequently associated with movement timing and is believed to be assisted by the motor system comprising primary, secondary motor cortices and the cerebellum. Conversely “Cognitively controlled timing” of lengthier intervals, is deliberated to involve a cortical–subcortical loop, engaging prefrontal areas, basal ganglia and parietal cortex subjecting to attentional modulation (Lewis and Miall 2003; Buhusi and Meck 2005). A meta-analysis of timing literature identified that cortical structures like prefrontal areas and SMA are activated in timing tasks of longer intervals whereas subcortical structures like basal ganglia and cerebellum are more engaged in sub second timing tasks (Wiener, Turkeltaub et al. 2010). Timing tasks demanding perceptual judgment more likely involve basal ganglia as compared to tasks demanding motor responses.

Conjunction analysis has found right inferior frontal gyrus (IFG) and bilateral SMA are being engaged in all timing tasks (Wiener, Turkeltaub et al. 2010). In timing tasks with longer intervals prefrontal cortex, particularly the right DLPFC, appears to be associated with greater demand because these intervals create working memory (Koch, Oliveri et al. 2009). Tapping to a metronome/beep, is usually projected to employ striato-thalamo-cortical system. Due to its part in error correction, controlling predictive movements (Bastian 2006) and interval timings, the cerebellum is also significant in these tasks (Diedrichsen, Hashambhoy et al. 2005).

6.2.2 Perception of beat and rhythm

Findings regarding beat and rhythm perception have thrown light on the brain actions in the course of covert synchronization to external stimulus. Covert synchronization generates an inner link among motor and sensory processes that might be likewise engaged in overt SMS. Imaging studies have presented that when subjects listen to auditory stimulus their motor systems are activated without performing any motor task (Grahn and Brett 2007; Chen, Penhune et al. 2008; Bengtsson, Ullén et al. 2009; Chen, Penhune et al. 2009; Grahn and McAuley 2009; Chapin, Jantzen et al. 2010), and this normally links SMA, basal ganglia, pre-SMA, PMC and cerebellum. The skill to identify the basic organization of a rhythm, like a proper beep, entails whole basal ganglia (Grahn and Brett 2009). Precisely, in reaction to an auditory stimulus basal ganglia are connected with endogenous generation and predicting the beat (Grahn and Rowe 2012).

The extent to which activation of auditory cortex is coupled with cortical or subcortical motor triggering depends on musical training and on salience of the beat (Chen, Penhune et al. 2009; Grahn and Rowe 2009). In conclusion, neural findings appear to verify the assumption that perception of a beep is an intrinsic skill (Honing 2012) particular to humans (Honing, Merchant et al. 2012). Moreover, it has been suggested that the rhythmicity of motor cortical oscillations modifies oscillations in the auditory cortex, which might as a result effect auditory perceptual processes (Schroeder, Lakatos et al. 2008; Schroeder, Wilson et al. 2010). Generally, the findings studied in this section appear to point to an innate link among sensory and motor systems concerning their participation in rhythm perception.

6.3 Neural connections of overt synchronization

Sensorimotor synchronization tasks most often include finger tapping. Finger-tapping tasks usually utilize SMA, inferior parietal cortex, PMC, primary sensorimotor cortex (S1 and M1), cerebellum and basal ganglia (Witt, Laird et al. 2008). Though, diverse task-specific factors might modify the neural mechanisms.

6.3.1 Paced versus self-paced tapping

The differences and similarities in the neural connections involved by paced and self-paced tapping can be studied employing synchronization–continuation paradigm. In humans, motor areas like SMA, sensorimotor cortex (SM1), and anterior cerebellum are generally active for both paced and self-paced tapping (Witt, Laird et al. 2008). But, former studies also recommended that motor or prefrontal areas are engaged to a larger extent in continuation as compared to in synchronized tapping (Repp 2005). While synchronized tapping associates the cerebellar–premotor network due to required audio-motor coupling (Chen, Penhune et al. 2009), and sensorimotor coordination (Molinari, Leggio et al. 2007), continuation tapping depends more on the inner representation of the certain sequence tempo, hence needing the working memory loop.

However, utilizing a simple, static visual metronome of recurring flashes (Cerasa, Hagberg et al. 2006) did not notice any dissimilarity in brain activity among continuation and synchronized tapping in both normal subjects and neuro-pathologies of Parkinson’s disease. Sensorimotor synchronization with auditory stimulus and with regularly moving visual stimuli (Ruspantini, Mäki et al. 2011) depends on alike sensorimotor coupling system that employs particularly the motor area, like PMC, whereas sensorimotor synchronization with fixed visual metronomes does not. This explanation appears steady with the results of modality differences in the neural activity for rhythm perception (Grahn, Henry et al. 2011).

6.3.2 Anti-phase versus in-phase tapping

When tapping in response to a beep in in-phase and antiphase coordination pattern, antiphase mode leads to higher activation in pre-SMA, thalamus, superior temporal gyrus, lateral cerebellum cingulate, dPMC and insula and this dissimilarity was detected in both imagined and executed tapping (Oullier, Jantzen et al. 2005). (Jantzen, Oullier et al. 2007) also found greater activity in lateral PMC, pre-SMA and parts of the cerebellum during antiphase coordination mode comparative to in-phase tapping.

Moreover, the difference in activity identified in these areas because of coordination mode was found during both synchronization and continuation paradigm (although in continuation the pacing signal was not existent any more), even after break interval of up to 9 s between these two phases. During synchronization, diverse temporal information is signified in these cortical and subcortical motor areas for in-phase and antiphase tapping. And continuation tapping may require this coordination-dependent temporal memory. The extent to which antiphase tapping becomes difficult depends on rate of pacing signal. As it escalates as the rate of the pacing signal increases thus leading to lesser tapping stability, relative to in-phase tapping with the similar growing rates (Repp and Su 2013).

6.3.3 Uni-manual versus bimanual tapping

In this section we will discuss the effects of tapping movements i-e., uni-manual versus bimanual tapping and overt versus covert tapping. (Pollok, Südmeyer et al. 2005) studied interhemispheric integration due to simultaneous bimanual tapping in response to an isochronous auditory sequence. MEG phase coherence (8–12 Hz) identified cortical coupling in a network encompassing bilateral SM1, posterior parietal and primary auditory cortex, PMC, cerebellum and the thalamus. Particularly interhemispheric coupling happened at PMC, cerebellum and posterior parietal cortex (PPC). The results point toward cortical integration of bilateral somatosensory and motor information, plus subcortical integration of motor timing signals, during performing simultaneous bimanual task.

(Serrien 2008) investigated the consequence of swapping from simultaneous bimanual tapping in synchronization paradigm to uni-manual tapping in continuation paradigm. During continuation, she found a greater interhemispheric connectivity (PMC, sensorimotor areas and SMA) in the beta band. She deduced this increase as a result of the augmented motor demand created by effector reorganization, probably as a consequence of overpowering bimanual coupling.

Covert (imagined) and overt tapping movements in synchrony to a pacing signal appear to share alike neural mechanisms, comprising superior temporal gyrus, SMA, PMC, inferior frontal gyrus, inferior parietal lobe and basal ganglia (Oullier, Jantzen et al. 2005; Osman, Albert et al. 2006; Stavrinou, Moraru et al. 2007). (Oullier, Jantzen et al. 2005) observed the neural difference among antiphase and in-phase tapping in both executed (overt) and imagined (covert) movements, with larger activations for antiphase tapping in the following areas: SMA, lateral cerebellum, basal ganglia, and PMC.

EEG and phase synchronization analysis was used by (Stavrinou, Moraru et al. 2007) to expose connectivity between cortical areas during imagined and executed finger tapping in response to an isochronous auditory metronome. They found a same pattern of synchronization and desynchronization in the beta band trailing the tone onset in both imagined and executed tapping Similar results were found during a perceptual task in beta oscillation (Fujioka, Trainor et al. 2012). Moreover, synchronized activation in the fronto-parietal area contralateral to the intentional finger was also seen for both overt and covert tapping.

7 Objective

The study had the following purposes:

- Inducing plasticity employing non-conventional methods in healthy subjects.
- To examine how practice of bimanual finger tapping in 2:1 mode resulted in improved performance implying practice driven plasticity.
- To investigate to what extent this plasticity effects learning of a subsequent motor task.
- Evaluate the performance of both protocols on the basis of accuracy over time.

PART II

METHODOLOGY

8 Methods

8.1 Subjects

A total of 39 right-handed healthy university students participated in this study Figure 1. They were randomly assigned to one of the three groups, (Group A: 8 males, 5 females, age: 25.23±1.78 years, Group B: 6 males, 7 females age: 24± 1.22 years, Group C: 7 males, 6 females, age: 24.30±2.05 years). All subjects signed a written informed consent before participation. Written and verbal instructions about the experiment were provided to each participant. The protocol was approved by the local ethics committee.

8.2 Experimental Overview

The subjects were seated in a comfortable chair two meters away from the screen. They were asked to place their arms on a table in a comfortable position for tapping on a touch pad. Subjects were studied in the Human System Lab (HSL), School of Mechanical and Manufacturing Engineering (SMME), National University of Sciences and Technology (NUST) Islamabad. The protocol was comprised of two tasks, i.e. a tapping task and a bimanual button pressing task. Former was used to induce the practice driven plasticity (Serrien 2009) and later was used to probe the effect of practice driven plasticity on learning a new task.

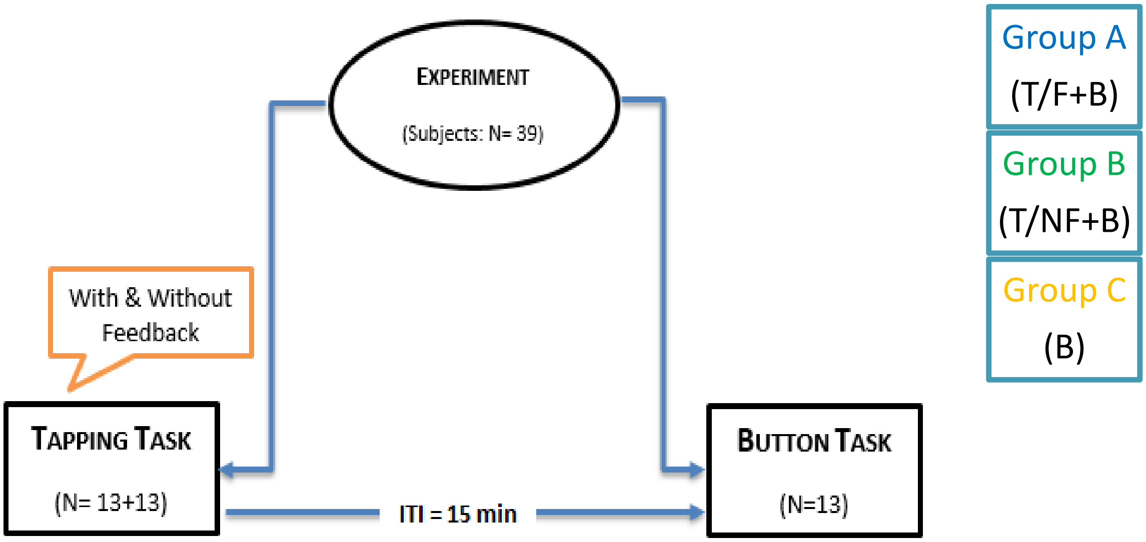

Figure 1 Methodology of experiment. N= number of subjects, T=Tapping task, F=feedback, NF= No feedback and B= Button task

8.3 Signal Acquisition

The hardware used for the conversion of analogue signals to digital signals was Powerlab® by ADInstruments Figure 2. Powerlab is a powerful and user friendly system which is used to record and analyze data acquired from physiological signals. It allows recording from 4 channels at a time. Powerlab hardware has a system time lag of 50-60 msec as mentioned in used manual for this hardware. After acquisition, analogue data is sent to a software called LabChart in which signal is amplified, filtered, sampled and then displayed as a digital signal on screen. Auditory stimulus generated by Psychtoolbox-3 is given to other CPU (to compute signals) through external trigger at the same time when beep is produced. The external trigger is sent through parallel port. The acquisition system is shown in detail in Figure 3;

Figure 2 Power Lab

8.3.1 Signal acquisition of Tapping Task

Analog signals from two resistor touch sensor are fed into input channels (Channel 1 and Channel 2) of power lab through BNC connector (by ADInstruments). External trigger is fed into input Channel 3 Figure 3.

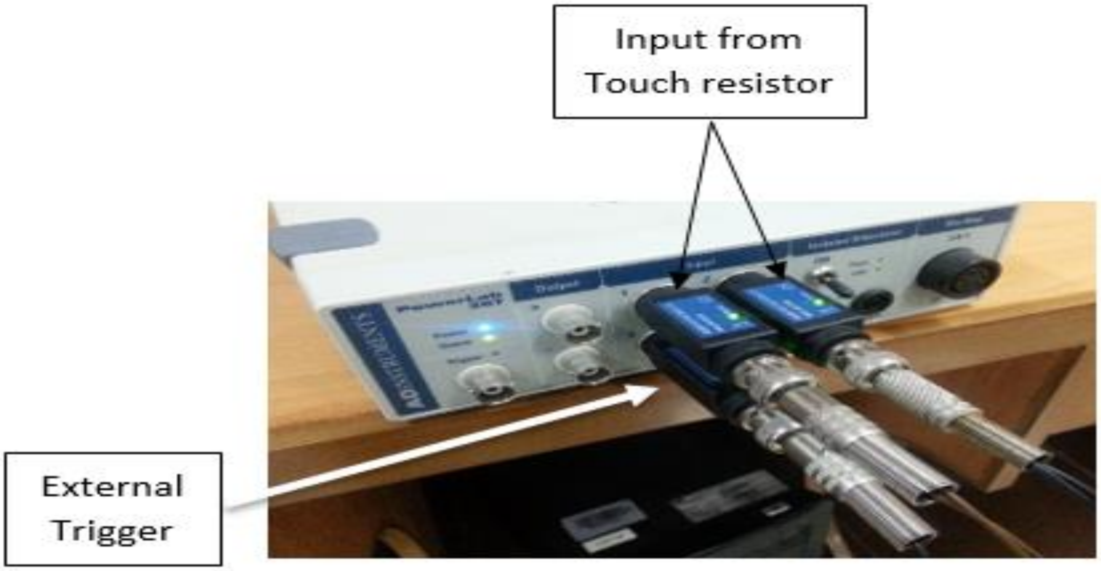

Figure 3 Signal Acquisition of Tapping task

8.3.2 Signal acquisition of Button Task

For button task signals were acquired through pulse transducer (ADInstruments) and push button (ADInstruments). Outputs from these two are fed into input channels of Power Lab. External Trigger is fed into Channel 3 of Power Lab Figure 4 (A,B,C).

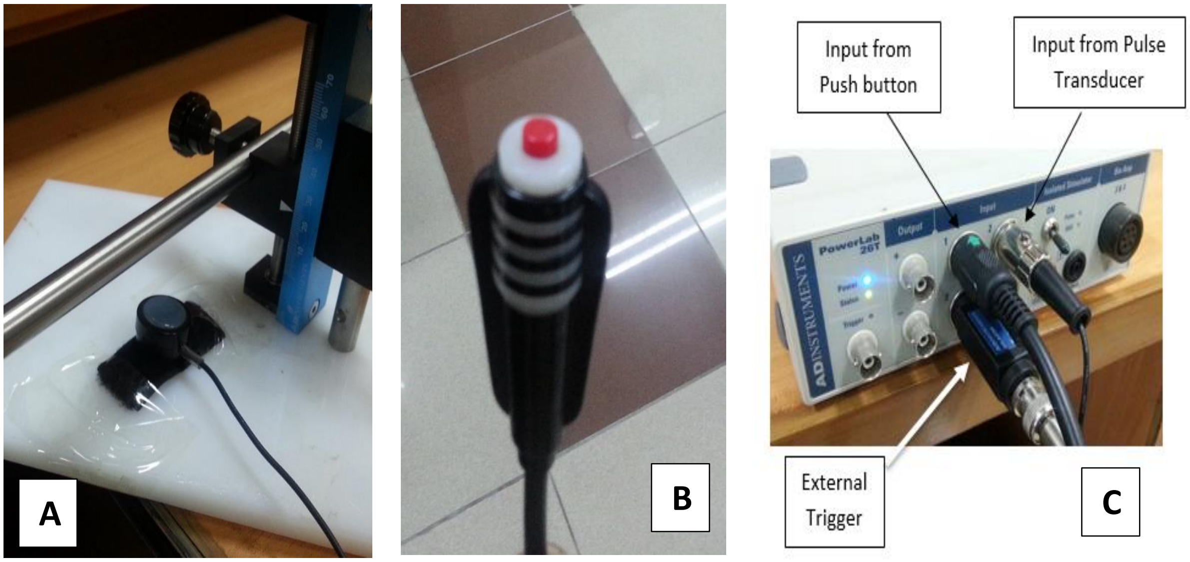

Figure 4 Signal Acquisition of Button task. A shows pulse transducer, B shows push button and C shows connections with Power Lab

8.4 Signal Processing

LabChart software is compatible with Matlab. Therefore, after receiving signal in LabChart, samples were sent to Matlab for computation. A buffer was created in Matlab that received data at a sampling rate of 1000 Hz from LabChart for 400 msec (400 samples).

8.5 Experimental Setup

8.5.1 Tapping Task

The tapping task was further divided into tapping task with performance feedback (T/F) and tapping task without performance feedback (T/NF). The subjects from group A performed ‘T/F and Button Pressing Task’ (T/F+B). The group B performed ‘T/NF and Button Pressing Task’ (T/NF+B) and Group C performed only ‘Button Pressing Task’ (B). Each subject of group A and group B performed the two tasks on the same day, inter task time interval was 15 minutes.

Tapping task (continuous practice of 2:1 task) was adopted from (Serrien 2009) .The participants were seated on a comfortable chair and were instructed to carry out bimanual finger tapping. Tapping was performed with index fingers on a locally made resistor touch sensor (fixed on a table) Figure 5 (A). Resistor touch sensor/pad is a simple circuit designed to turn on or off a device on output. It works by sensing on that basis it activates or deactivates a device connected to the output. One end of resistor touch sensor is connected to 9V power supply and the other end is connected to base of the transistor. When a user touches the **‘resistance touch pad’** the flow of electricity activates the transistor which in turn activates the LED at the output Figure 5 (B,C).

Subjects were instructed to tap according to 2:1 mode. The 2:1 mode requires tapping of both index fingers simultaneously for one tap followed by tapping of non-dominant (left) finger, while keeping dominant (right) index finger still at peak upward position Figure 6. Timing was externally paced and auditory stimulus (beep) was generated randomly in-between 700 ms to 800 ms through MATLAB 2012 and Psychtoolbox-3 (PTB-3). An auditory cue at the beginning represents the start of task after 3 sec. Tapping task was consisted of 14 sessions with 60 taps per block. Simultaneous tapping should be done in response to a low frequency beep followed by tapping of non-dominant index finger at high frequency beep. Subjects were instructed to tap immediately after hearing a beep and should complete it within 400 ms (response time). For task (T/F) visual performance feedback was provided on the screen by means of a colored bar representing the response time (a green color bar means successful execution with in 400ms and red bar means error) Figure 8. For (T/NF) task they were instructed to tap immediately in response to an auditory stimulus only and there was no colored bar to show the response time Figure 9.

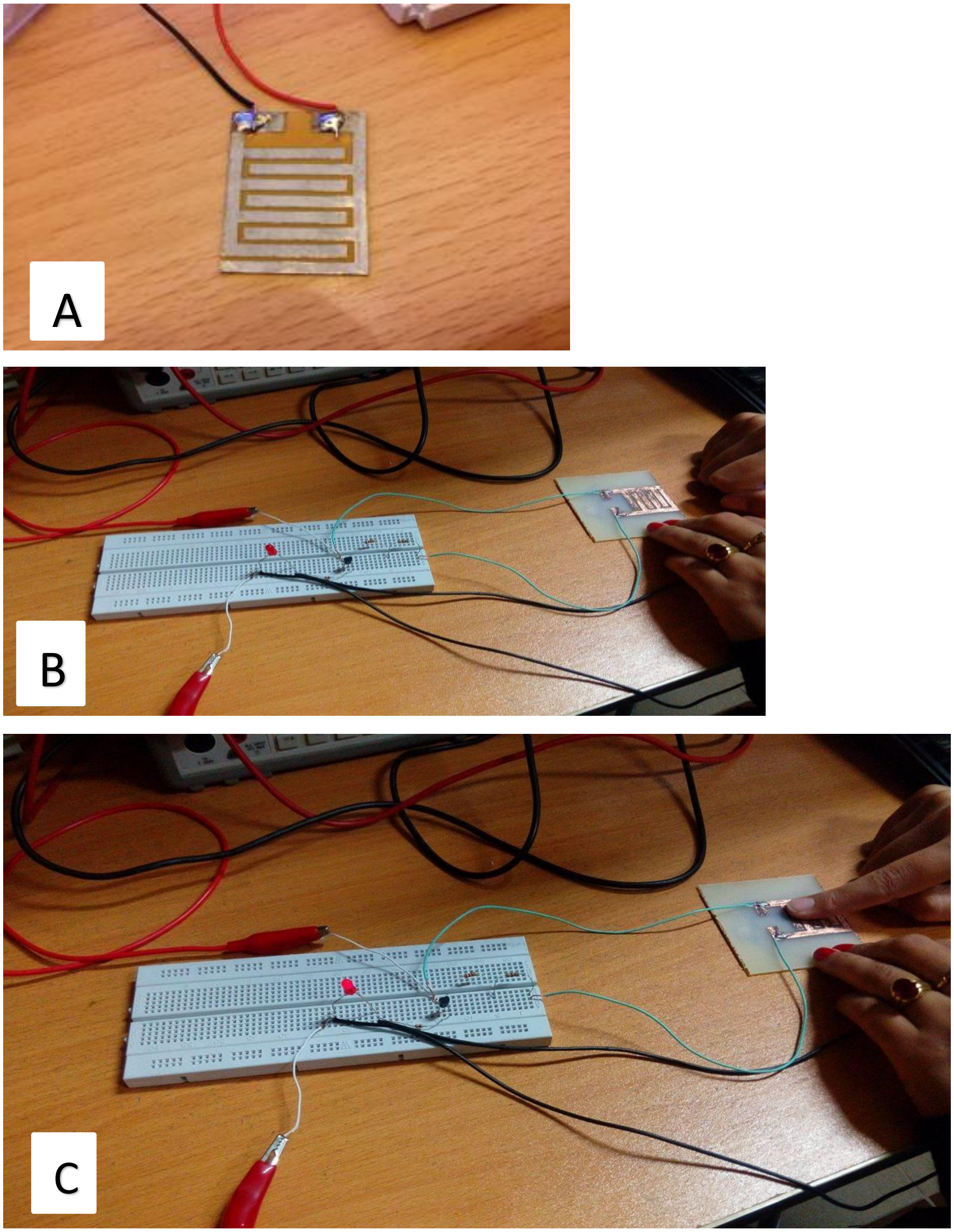

Figure 5 Resistor touch pad. A shows resistor touch sensor, B shows connection with LED at output and C shows touch sensor touched by index finger resulting in turning on of LED at output.

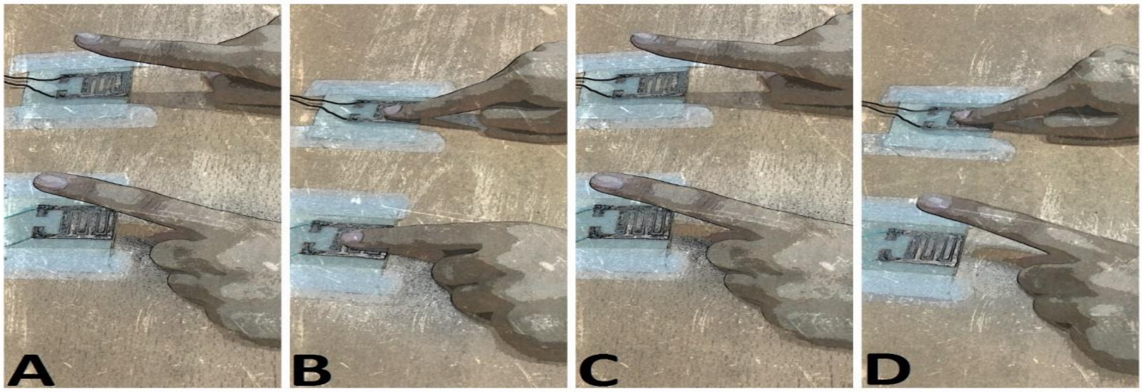

Figure 6 Tapping Task according to 2:1 mode. A Starting position for tapping task. B Tapping of both index fingers simultaneously for one tap. C Peak upward position. D Tapping of non-dominant (left) index finger and pausing dominant (right) index finger at peak extension

8.5.2 Button Task

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 7. Timing was externally paced and auditory stimulus with inter trial interval of 550 ms - 650 ms was generated through MATLAB 2012, PTB-3. An auditory cue was generated at the start of the bimanual button task representing the start of the task after 3 sec. Vertical bar depicting response time (< 400 ms) was provided on the screen of the monitor as a visual feedback Figure 10. Subjects were instructed to perform the task immediately after hearing beep and synchronize their tap with second button press. Lab Chart software (ADInstruments, Australia) was used to record the data in all tasks. The data was stored for further analysis.

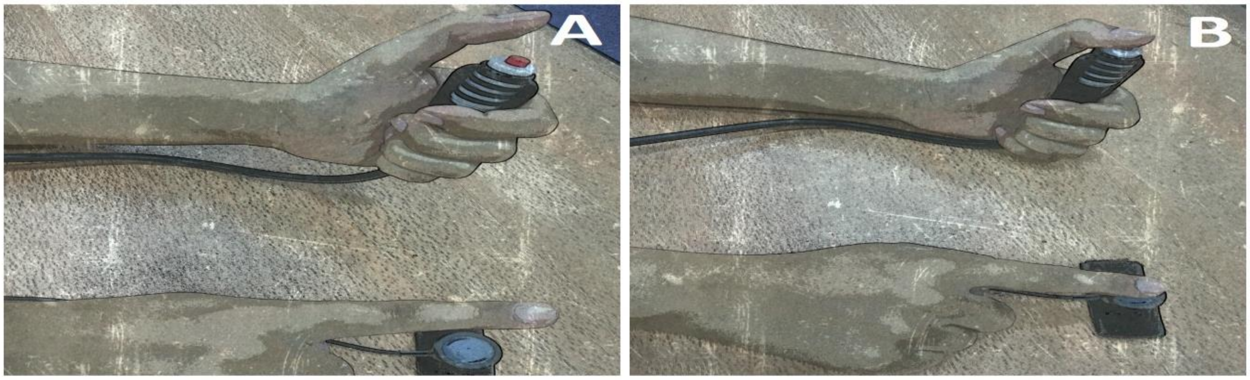

Figure 7 Button Task. A Holding push button in non-dominant (left) hand and pulse transducer is fixed on table. B Pressing of push button twice with thumb of non-dominant hand and pulse transducer with index finger of dominant (right) hand.

8.5.3 Timing Diagrams

8.5.3.1 Tapping Task with Feedback (T/F)

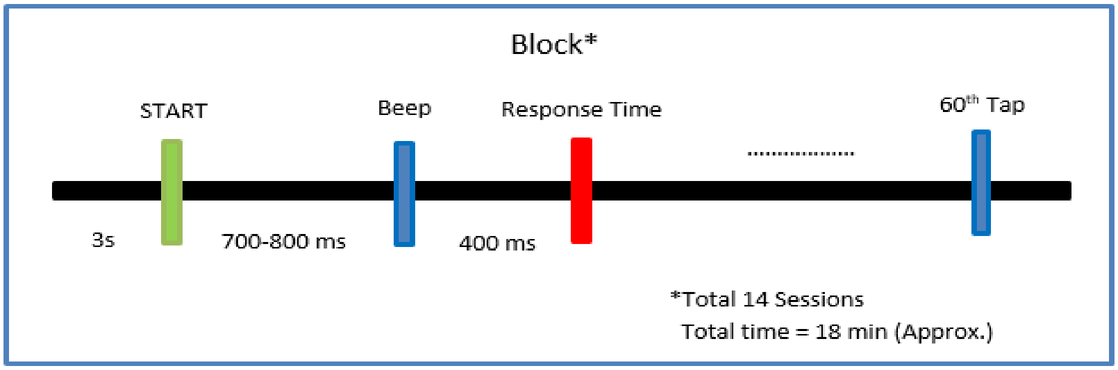

Figure 8 Timing diagram of Tapping task with feedback. Tapping task consist of 14 trials. Each session comprised of 60 taps.

8.5.3.2 Tapping Task without Feedback (T/NF)

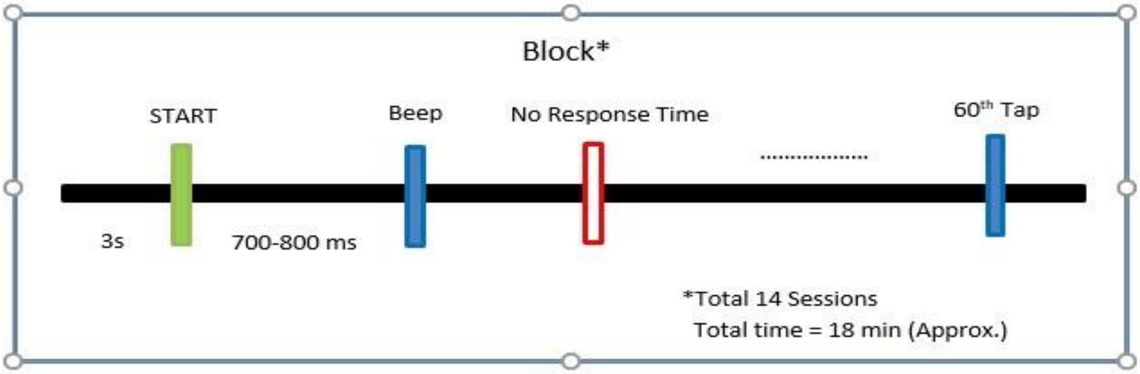

Figure 9 Timing diagram of Tapping task without feedback. Empty red box depicts absence of Response time.

8.5.3.3 Button Task (B)

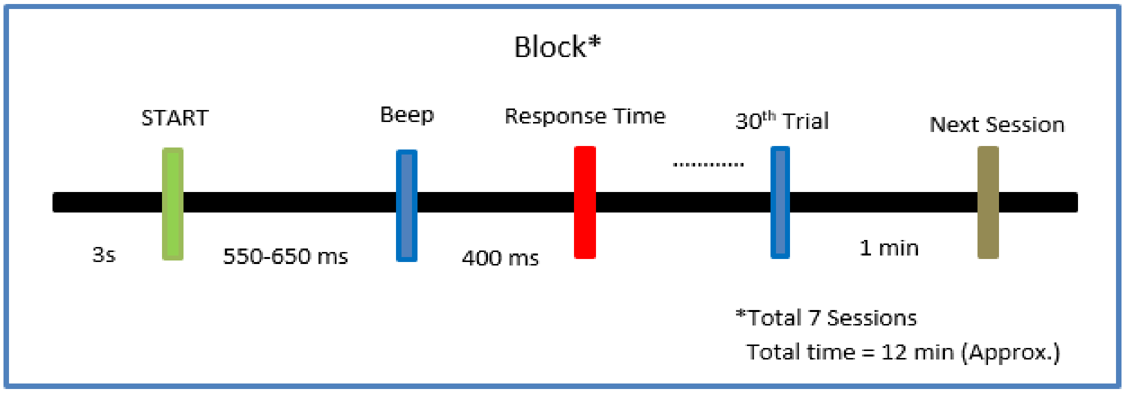

Figure 10 Timing diagram of Button Task. Button task consists of 7 sessions. Each session includes 30 trials.

8.6 System Performance

The system performance was evaluated based on task accuracy over time.

$$Accuracy(\%) = \frac{Number\ of\ correct\ trials}{Total\ number\ of\ trials} \times 100$$

PART III

RESULTS

9 Results

The assessment is based on behavioral findings in terms of error reduction with sessions and two kinds of evaluations are being made. First, it is assessed how short training of continuous 2:1 task associates with improved motor experience with and without performance feedback. As simple rhythms with non isofrequencies have complex task demands so the suggestion is made that performance feedback will assist the task. Second, it is examined to what extent this practice driven plasticity impacts on the learning of a subsequent motor task.

For each task the data was divided into start of the learning (averaged of first two sessions) and end of learning (averaged of last two session). Statistica software (StatSoft Inc., Tulsa, USA) was employed to analyze the data. The student t-test for dependent samples was performed on averaged sessions (early, late) of all groups. For T/NF, T/F, B, T/NF+B and T/F+B, group comparisons were made by ANOVA. All subjects showed learning through early to late sessions due to practice. The results were considered significant if $p<0.05$.

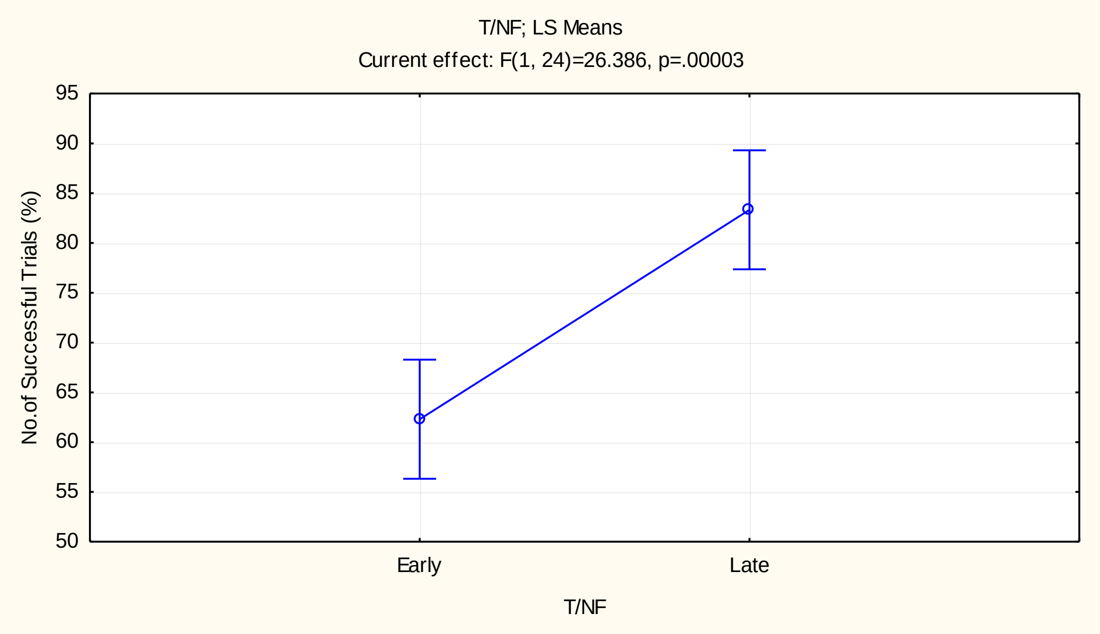

Figure 11 Accuracy of Tapping task without feedback. Increased accuracy was observed at the end of practice than at the start of practice, implying practice driven plasticity.

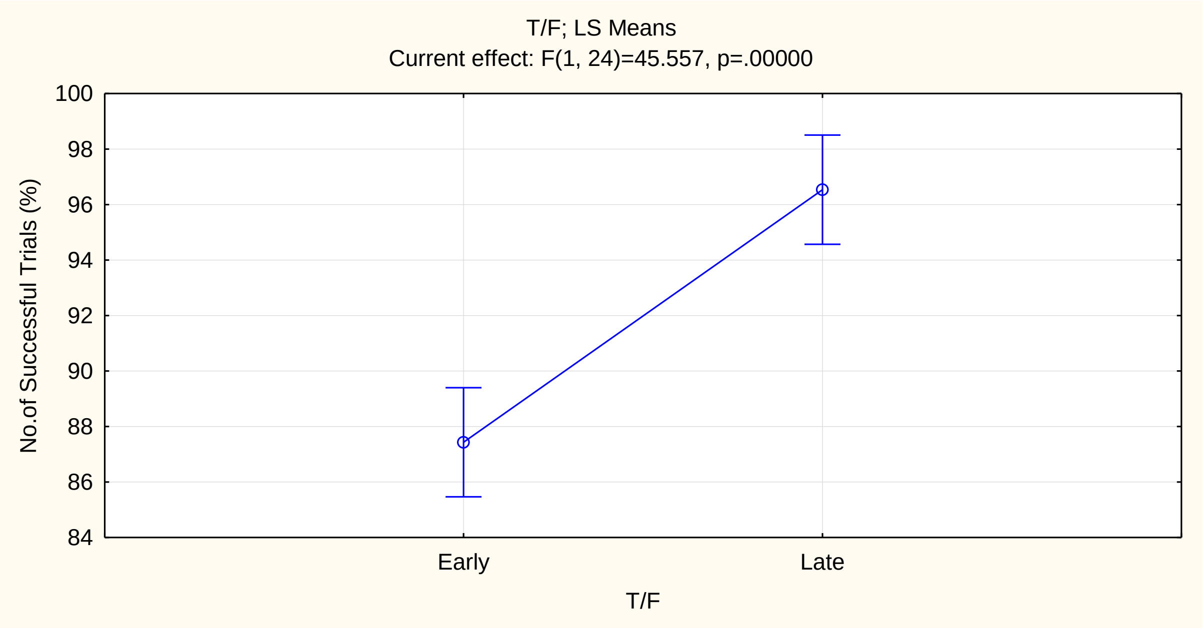

Figure 12 Accuracy of Tapping task with feedback. Increased accuracy was observed at the end of practice than at the start of practice, implying practice driven plasticity.

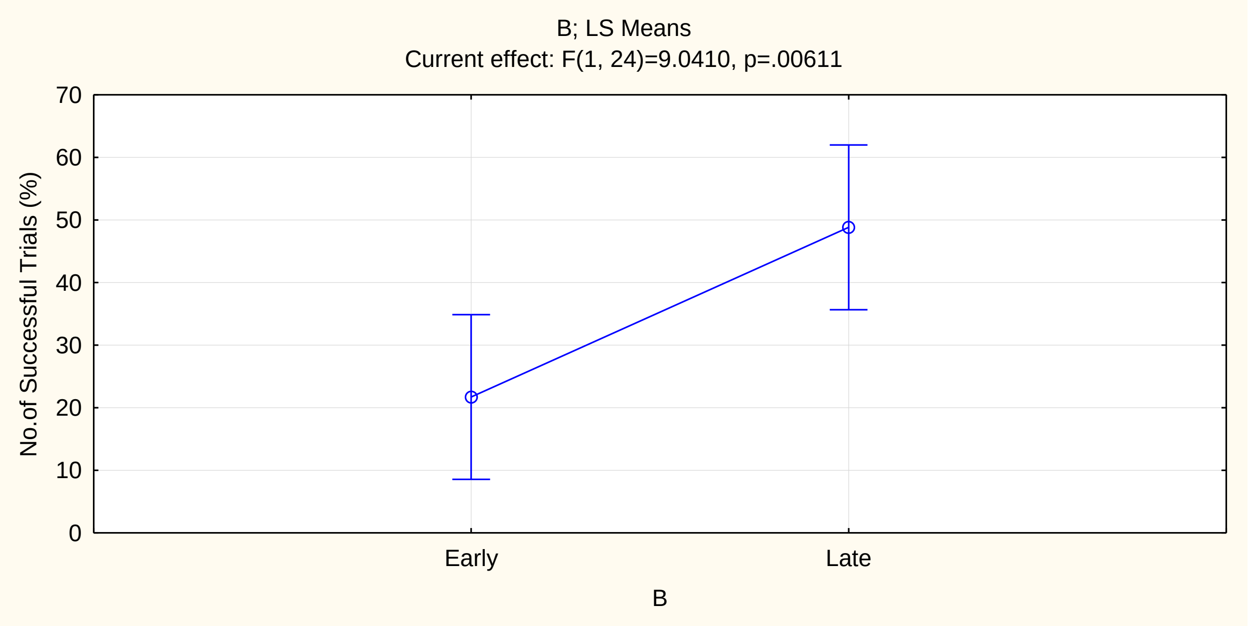

Figure 13 Accuracy of Button task. Improved performance was observed at the end of Button task as compared to Start of the task implying learning.

To probe the results of significant ANOVA, multiple independent planned comparison was performed. Early session comparison of T/F & T/NF are shown in Figure 14.

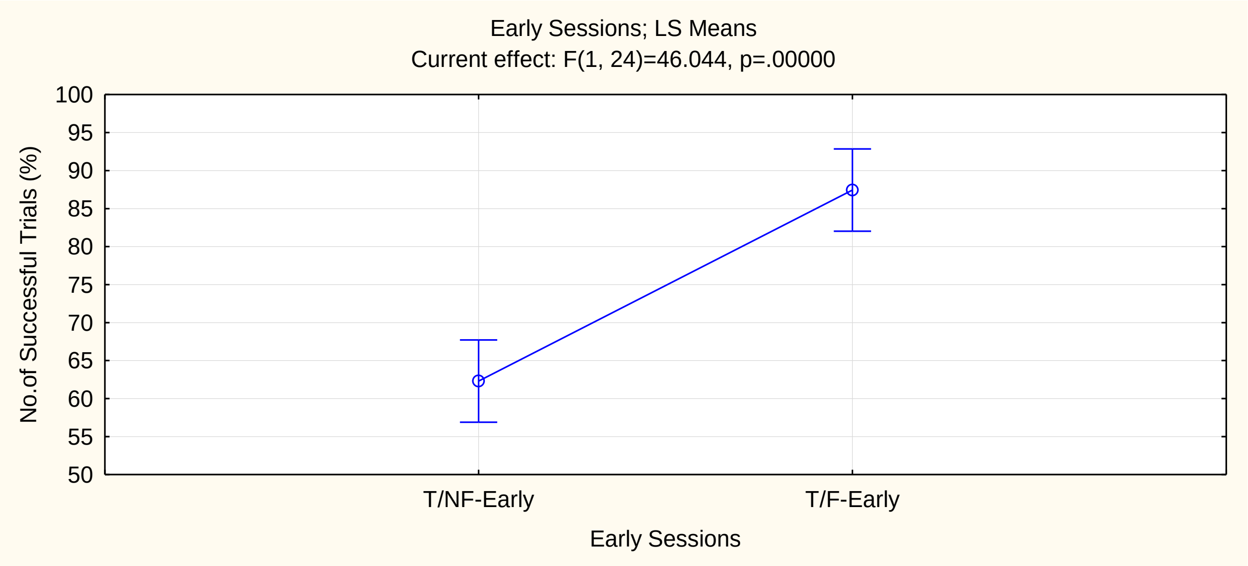

Figure 14 Early session comparison of T/F and T/NF. Increased accuracy at the start of Tapping task with feedback was observed as compared to start of Tapping task without feedback implying feedback improves performance.

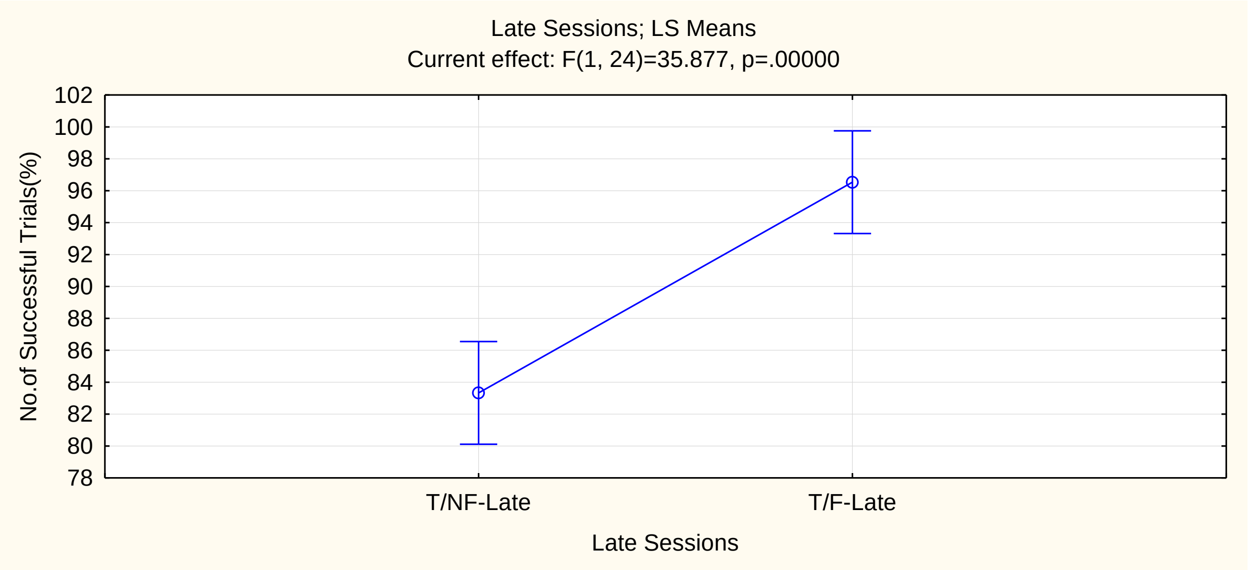

Figure 15 Late session comparison of T/F and T/NF. Increased accuracy at the end of Tapping task with feedback was observed as compared to end of Tapping task without feedback implying feedback improves performance.

While their late sessions comparison are also shown Figure 15. Planned comparison compares early and late sessions of all three groups (Figure 16 , Figure 17).

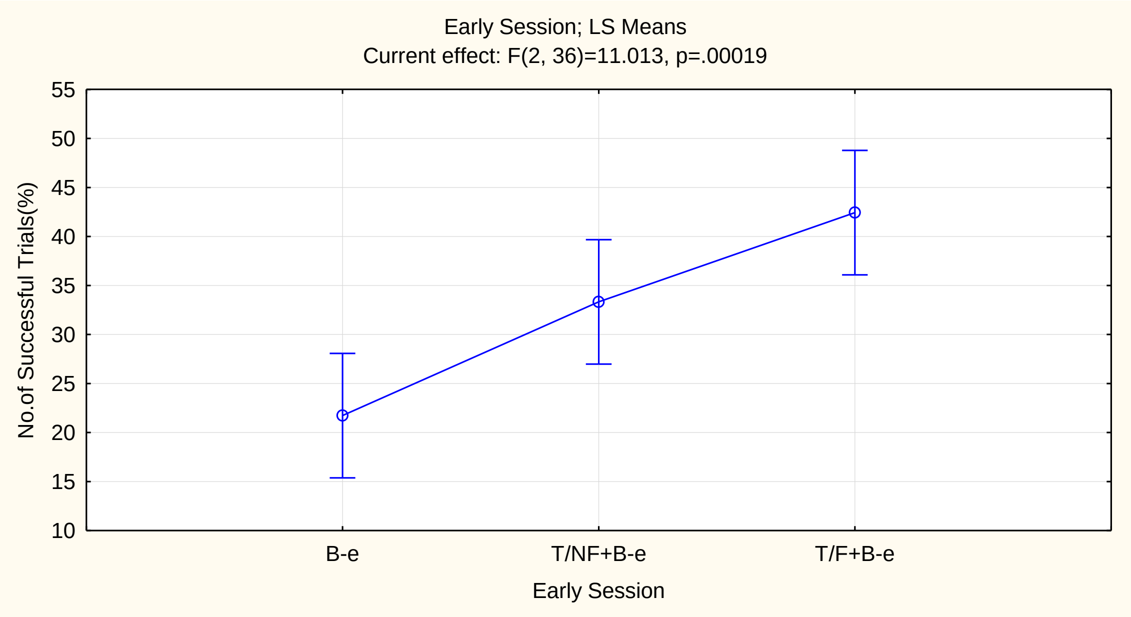

Figure 16 Early Session comparison of T/F+B, T/NF+B and B. Higher accuracy at the start of T/F+B was observed as compared to other two groups.

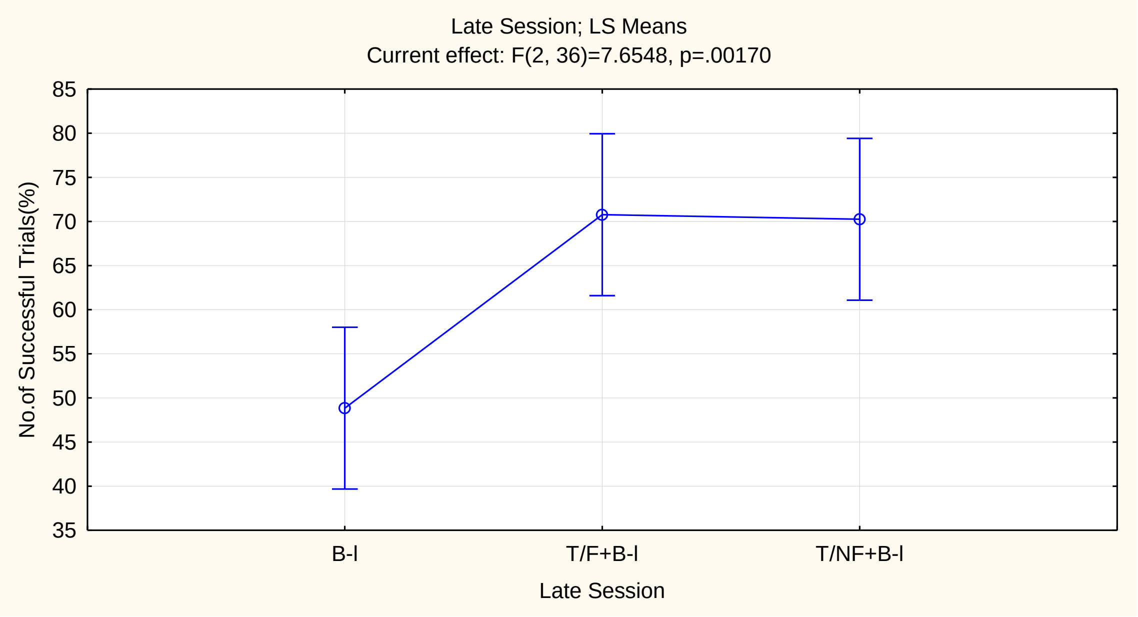

Figure 17 Late Session comparison of T/F+B, T/NF+B and B. Higher accuracy at the end of T/F+B & T/NF+B was observed as compared to group B.

9.1 Tapping task with feedback (T/F)

The subjects carried out bimanual finger tapping in 2:1 mode with performance feedback. Accuracy scores were evaluated. The student t-test on sessions (early, late) presented significant effect, F (1,24) = 45.551, p=.00000. It indicated that accuracy scores at the start of the practice of T/F was lesser as compared to the end of practice.

9.2 Tapping task without feedback (T/NF)

The subjects performed bimanual finger tapping in 2:1 mode without performance feedback. Accuracy scores were calculated. The student t-test on sessions (early, late) demonstrated significant effect, F (1,24) = 26.382, p=.00003. It revealed that accuracy scores at the end of the practice of T/NF was higher than that achieved at the start.

9.3 Comparison of T/F and T/NF

T/F performed better than T/NF in both early (F (1,24) = 46.035, p=.00000) and late (F (1,24) = 35.882, p=.00000) sessions Figure 18.

9.4 Button task (B)

The subjects performed Button task alone in which they were asked to press push button twice with thumb of non-dominant hand along with pressing of pulse transducer once with index finger of dominant hand. The student t-test revealed significant effect on both (early, late) sessions, F (1,24) = 8.6817, p=.00704. It showed higher accuracy at the end of practice of button task as compared to the start.

9.5 Comparison of T/F+B and B

Multiple planned comparison shows that group T/F+B performed better than group B in both early F(1,24)= 21.15969, p=0.000051 and late F(1,24)= 11.75019, p=0.001539 sessions.

9.6 Comparison of T/NF+B and B

According to results of planned comparison performance of group B was lower than group T/NF+B in both early F(1,24)= 6.282002, p=0.016854) and late F (1,24)= 11.20690, p=0.001919) sessions.

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9.7 Comparison of T/F+B and T/NF+B

Planned comparison on both (early, late) sessions of groups T/F+B and T/NF+B showed diverse observations. In particular no significant effect was observed for late sessions of both groups F (1,24) = 0.006429, p >0.05 p=0.936535). In contrast ANOVA on early sessions showed significant effect F (1,24) = 4.383055, p=0.043404). Performance of T/F+B at the start of practice was better than T/NF+B whereas at the end of the practice there was no significant difference. This might be due to presence of performance feedback which has augmented the performance of T/NF+B .

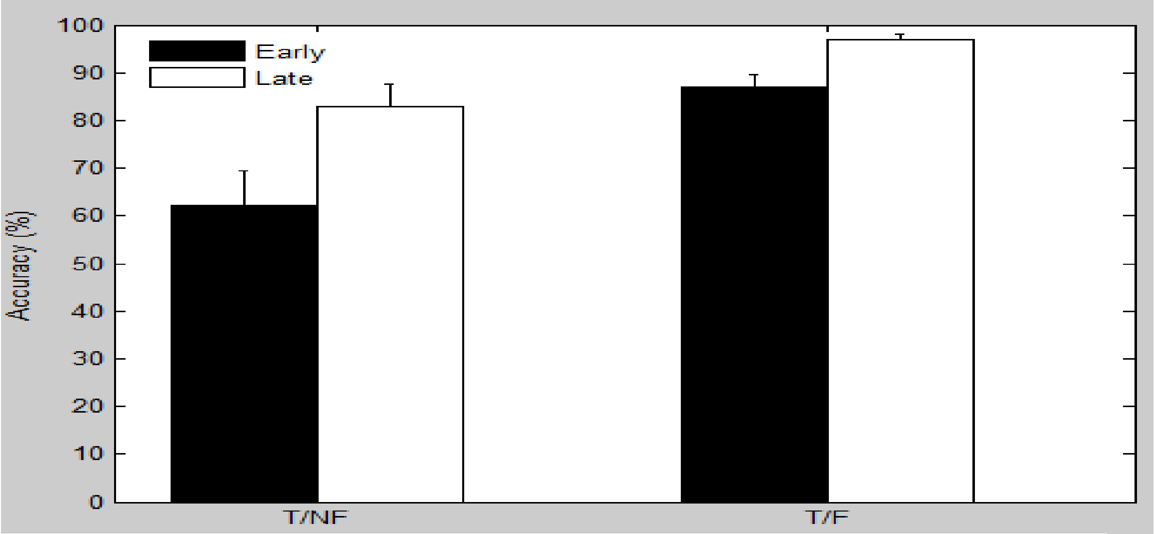

*Figure 18 Tapping task with and without feedback: Behavioral accuracy of Tapping task without feedback (T/NF) and Tapping task with Feedback (T/F). Over all for all participants in respective groups, early (First two sessions) and late (last two sessions) sessions, accuracy scores were averaged. Early and late sessions are shown. Error bars indicate Standard Deviations (SD) from the mean values. The lines show mean error and error bars show 1.96*SD.*

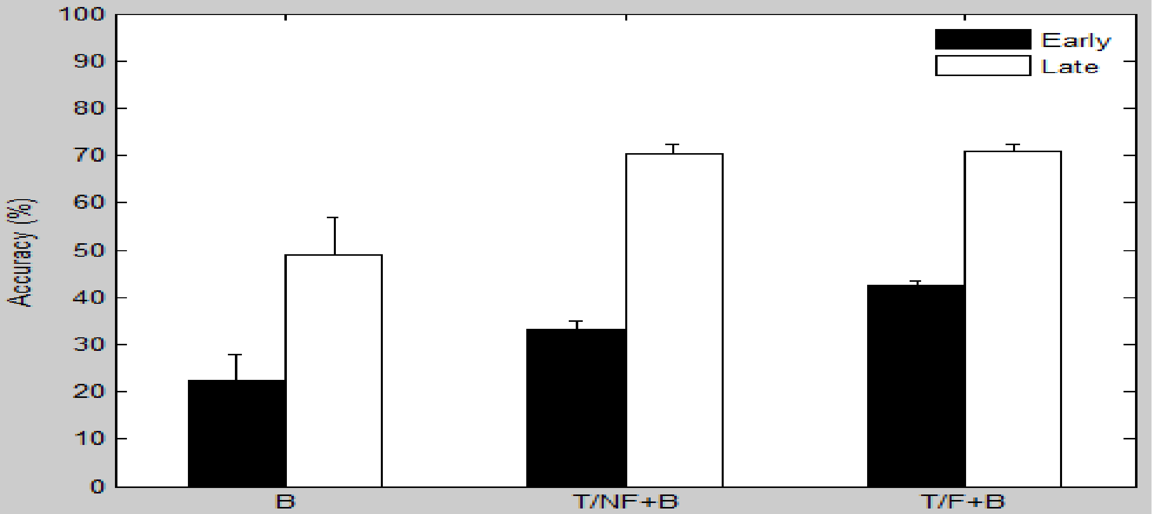

Figure 19 Accuracy scores linked with practice for different groupings (Tapping task with feedback and button task (T/F+B), Tapping task without feedback and Button task (T/NF+B) and Button task (B) alone): Over all for all participants in respective groups, early (First two sessions) and late (last two sessions) sessions, accuracy scores were averaged. Early and Late sessions are shown. Error bars represent Standard Deviations (SD) from the mean values.

PART IV

DISCUSSION & CONCLUSION

10 Discussion

10.1 Summary

The aim of the study was to induce plasticity through bimanual finger tapping task over training sessions; and to determine to what extent this practice driven plasticity effects the performance and learning of subsequent bimanual motor task.

In the current study, subjects performed bimanual finger tapping with a 2:1 frequency ratio under with and without feedback condition. Continuous recurrent tapping according to 2:1 mode induces practice driven plasticity (Serrien 2009). 2:1 mode requires a strategy that involves the effectors moving simultaneously for one tap followed by tapping once by fast effector while the non-dominant index finger pauses at peak upward position. The motor performance was evaluated in terms of task accuracy at the start and at the end of training. The results show substantial performance improvements at the end of practice. It also infers a basic metrical coordination with an explicit portrayal of temporal objectives (Semjen 2002). Regarding rhythmical movements, the preference present itself via 1:1 that is executed following an in-phase and anti-phase mode. This preferred repertoire reveals an intrinsic behavior that can be performed efficiently without practice (Serrien, Strens et al. 2002). Anti-phase arrangement is normally less effectively executed than in-phase due to more intricate task requirements. Also complex movements involving those simple rhythms having one limb’s frequency being an integer multiple of other limb (2:1 etc.,) or polyrhythms are difficult to execute and require training (Peper, Beek et al. 1995).

The results from continuous practice of 2:1 task with feedback showed better behavioral performance accentuating short training of task linked with improved motor performance. For tapping task without feedback, the participant’s behavioral performance improved, though it was inferior compared to the tapping task with feedback. Simple rhythms with non-isofrequency (2:1) or polyrhythms (5:3 etc.,) would require feedback-assisted training to be executed proficiently (Kovacs and Shea 2011). This indicates that concurrent feedback assists the performance of task and its removal would deteriorate the performance.

Training structure impacts acquisition of motor skills. Continuous practice of 2:1 task was based on blocked practice (Serrien 2009). Blocked practice schedules (execution of trials separately) give better performance than random practice or practice under interleaved conditions during acquisition (Shea and Morgan 1979). Training under diverse schedules involves different neural substrates (Dayan and Cohen 2011) including M1 (Kantak, Sullivan et al. 2010) and the SMA (Tanaka, Honda et al. 2010). Encoding of motor memory due to random practice schedule is linked with quick shifting from SMA to other brain areas like parietal cortex or striatum (Tanaka, Honda et al. 2010). In other words, random practice might cause rapid memory stabilization and gives better performance at retention (Shea and Morgan 1979). It is also acknowledged that medial areas (including SMA) are vital for coordination, which might link with requirements of intricacy, timing and restriction (Macar and Vidal 2002; Serrien, Strens et al. 2002).

Bimanual button pressing task employs the strategy to press push button twice with non-dominant thumb along with tapping once with index finger of dominant hand. Subjects were asked to synchronize their tap with second button press. This scheme makes bimanual performance more difficult than the reverse arrangement (Semjen 2002). Bimanual button task was based on blocked practice. Blocked practice gives better performance during acquisition as compared to at retention (Shea and Morgan 1979). Practice conditions involving high degree of interference lead to better performance at retention (Maslovat, Chus et al. 2004). The results from Bimanual button pressing task alone showed enhanced task performance although it was inferior to both conditions of tapping task (with and without feedback) and Bimanual button pressing task.

The combined results indicate the influence of tapping task on Bimanual button pressing task. Competition among pre-existing and new behavior determines acquisition of a skill, proposing bidirectional impacts among both behaviors (Zanone and Kelso 1992). For consolidation of new acquired skills, this source of competition is somewhat alike to the notions of anterograde (impact of earlier learning on new one) and retrograde interference (impact of new one on previous one) (Krakauer, Ghez et al. 2005).

10.2 Motor Learning

Different paradigms of motor learning might suggest that there are more differences as compared to similarities between the learning of diverse motor tasks. Though, mathematical relationships among features of movement like speed, kinematics and accuracy, suggest that there are fundamental principles in motor learning and motor behavior and these similarities may possibly reveal underlying characteristics of the brain physiology and network function. Some of these fundamental characteristics are likely to be dependent on molecular principles of neuroplasticity (e.g. interference etc.,) while other characteristics are likely to reflect the interaction and differential dependency between different brain networks (e.g. synchronization etc.,) (Teo 2009).

Motor learning is likely to be an emergent phenomenon from the interaction of multiple brain regions rather than isolated neuroplasticity occurring in only one cortical or subcortical brain region. However, it is likely that within these multiple brain regions neuroplasticity is also what allows the interaction to remain dynamic. Also, the likely emergent nature of motor learning does not exclude the possibility that molecular and physiological mechanisms set rules and limits to motor learning (Teo 2009).

10.3 Methodology

10.3.1.1 Why Bimanual Finger Tapping

There are many motor learning paradigms available in literature. These methods are efficient and produces good results. However, these techniques are effective for different purposes.

It is clear that sequence learning is a paradigm that test learning while locomotor adaptations and force field adaptations are more towards testing adaptations. There are some deficiencies present in sequence learning paradigm comprising lack of generalization and ecological validity. Conversely it is one of the widely used paradigm in motor learning. Some have termed Ballistic motor learning as “use dependent” or “practice” effect rather than learning. This also reflects that it is an elementary form of motor learning.

Heterogeneity of sensory and visual feedback used in visuomotor transformations makes it complex to compare tasks within this category. While force field adaptation involves a robotic arm in reaching movements. This form of motor learning doesn't depend on primary motor cortex (Baraduc, Lang et al. 2004). This paradigm is widely studied in robotics but its relevance on human motor control is still unclear. Locomotor adaptation focusses on lower limbs.

Our focus was on upper limbs comprising bimanual rather than uni-manual movements. SRTT involves bimanual movements but these bimanual movements are performed in a sequential manner. Our scope was to perform bimanual movements simultaneously. So bimanual finger tapping was found to be best suitable paradigm for our study. Finger tapping task involves the subjects to perform bimanual finger tapping synchronously and asynchronously. This paradigm is easy, flexible and can incorporate several amendments. Finger tapping can be easily employed in studies of normal as well as in neuro-pathologies.

10.3.2 Time Delay

Time delay of 130 -170 ms was present in the study. This include both software and hardware delays. PowerLab has built in delay of about 50 – 60 ms as mentioned in hardware manual. This time delay can't be catered. Temporal delay on software side was minimized by keeping algorithm simple. Output latency of 23 ms was present in Psychtoolbox-3. Output latency is defined as time between making a sound in software and finally hearing it. This time lag is acceptable for the system if output latency is further minimized the it gives jittering effect in sound which is unacceptable.

10.4 Why Parallel Port

A parallel port utilizes a standard DB25 connector, which has 25 pins, each with a different purpose. DB25 comes in both male and female variants. DB25 male consists of 25 pins while DB25 female has 25 holes. DB 25 consists of two rows, with top row having 13 pins and bottom row with 12 pins. Standard parallel port has 8 data pins, which are usually TTL logic outputs, High representing 1 (+5V) and low representing 0 (0V). Pins 18- 25 are ground pins. Our study employed DB25 female.

Signals of finger tapping task was acquired through PowerLab connected to a separate computer system. Whereas auditory stimulus was generated by a separate system. These two systems can be connected by two ways: either through parallel programming or through parallel port. Parallel programming is intricate and requires proficiency in programming skills. External trigger through parallel port is much easier way as compared to parallel programming. So we utilized parallel port for sending external trigger (auditory stimulus). Parallel port programming includes some basic steps like: creation of digital input/output object, adding of pins to be used as output pins in created object and the last step is to send data to output lines.

10.5 Implications

It is possible to induce plasticity in human brain utilizing bimanual finger tapping. Further neural activation patterns utilizing EEG can be used reflecting inter, intra and midline connectivity of hemispheres. Perceiving the impact of practice structure on motor skill consolidation and retention has promising effects, for example this information might transform into developed neurorehabilitation based on training afterwards brain injury.

10.6 Limitations

The study was performed on 13 healthy subjects within each group. Larger sample sizes will represent the population better. The study is based on behavioral findings so neural activation patterns were not determined at this stage. Although tapping task was an adoption from (Serrien 2009) and our study has replicated the behavioral results but EEG analysis needs to be done in order to confirm the inter hemispheric interactions. Moreover, if one wants to study the trend during experiment then an offline data analysis will be performed. This will also help us to provide neurofeedback to the subject as well. Options are always available for reduction of temporal lag. Minimizing the lag could lead to improvement in performance.

11 Conclusion

Motor skills are normally gained via practice. This advancement encompasses acquirement of the certain task requirements by overruling intrinsic behavior. Intrinsic behavior depicts those configurations that can be performed with low variability and high accuracy without any practice. By evaluating influence of practice driven plasticity on subsequent motor task the present study showed that continuous practice of bimanual finger tapping in 2:1 mode reveals an improved behavioral performance. Finger tapping in 2:1 mode was performed under two conditions: tapping task with feedback and tapping task without feedback. Results reveal that presence of feedback assist task leading to better performance whereas absence of feedback deteriorate performance. This short training linked with enhanced motor experience results in practice driven plasticity. This practice driven plasticity can be used to enhance the learning of a new bimanual motor task. Results suggest that continuous practice of tapping task induces plasticity which may have substantial implications on learning of a subsequent motor task.

12 References

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