THE IMPACT OF TRANSIENT VISUAL DEPRIVATION AND PROPRIOCEPTION IN MOTOR SKILL LEARNING AND ACUTE CORTICAL EXCITABILITY

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ABSTRACT

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The purpose of the present study was to assess the impact of transient visual deprivation in complex motor skill learning and motor skill training induced acute cortical excitability in healthy subjects. Training induced alterations in proprioception was another field of interest investigated in this study. The study investigated three separate training conditions induced motor cortex plasticity effects with transcranial magnetic stimulation. Training conditions used in this study were eyes open, eyes closed and imaginary training. Imaginary training was added to clarify the effect of eyes closing motor skill training. The motor skill training was performed with tibialis anterior muscle as ankle dorsiflexion movement.

Transcranial magnetic stimulation (TMS) was the main method of investigation of the cortical site plasticity. With TMS, motor skill training induced plasticity changes were researched as altered motor evoked potentials elicited from the tibialis anterior cortical area. With single-pulse TMS, the I/O curve represented the excitability changes and strength of the corticospinal tract. Paired-pulse TMS elicited SICI represents the inhibitory phenomenon in the motor cortex. Spinal level excitability changes were assessed with peripheral electrical stimulation. Maximal H-reflex of tibialis anterior represented spinal reflex pathway excitability alterations. The motor skill training was performed with the right ankle as a force-time curve, with separate emphasis of force and rhythm aspects.

The development in 20 minutes (40 trials) of motor skill training was largest in eyes open training condition. Imaginary training condition had indications of the largest change in the rhythm part. Transient visual deprivation protocol showed indications of increased excitability in every I/O curve intensity and a significant increase was observed after imaginary training. The intracortical inhibition indicated to reduce after training performed with transient visual deprivation protocol. However, the change was not significant. Spinal excitability showed a lack of statistical support, but indications of the reflex pathway alterations were observed in the imaginary training condition. Eyes open training pre value in proprioception was significantly less compared to imaginary training and post values did not differ significantly. Eyes open showed indications of the largest change.

The results indicate that vision acts as a dominant sense in motor skill learning, but it also seems that sensorimotor training affects the learning process. The excitability of the corticospinal tract seemed to increase when the motor skill training was performed with transient visual deprivation protocol, and imaginary training had a significant effect. The probable reason behind non-visual processing might arise from the change between cortical level performance or learned focused attention. The results indicate that change in motor skill training performed with transient visual deprivation might be acquired via compensated mechanisms, such as enhanced corticospinal level excitability, decreases in the intracortical inhibition, and proprioceptive feedback processing. Indications of acquired accuracy and rhythm after imaginary training was showed, but the speed of performance seemed more related to physically performed training. A probable explanation for the development in this type of motor skill training might lie in increased connection efficacy in existing synapses, motor cortex representation area expansion, and enhanced proprioceptive processing.

Key Words: Transient visual deprivation, proprioception, plasticity, motor cortex & transcranial magnetic stimulation.

ABBREVIATIONS

aMT	Active Motor Threshold
BDNF	Brain-derived Neurotrophic Factor
CNS	Central Nervous System
CS	Conditioning Stimulus
EMG	Electromyography
FP	Force Part in Motor Skill Training
H-Reflex	Hoffman Reflex
I/O curve	Input-Output Curve
LTD	Long-term Depression
LTP	Long-term Potentiation
M1	Primary motor cortex
MEP	Motor Evoked Potential
Max M-wave	Maximal M-wave
MVC	Maximal Voluntary Contraction
PAS	Paired Associative Stimulation
rMT	Resting Motor Threshold
RP	Rhythm Part in Motor Skill Training
rTMS	Repetitive Transcranial Magnetic Stimulation
TA	Tibialis Anterior
TS	Test Stimulus
TMS	Transcranial Magnetic Stimulation
SICI	Short Interval Intracortical Inhibition
SOL	Soleus

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1 INTRODUCTION

Skill training is thought to represent a change or improvement in perceptual, cognitive and/or motor performance after a specific type of exercise (Green & Bavelier 2008). Skill training induced performance alteration can happen after different timeframes of training (Green & Bavelier 2008). There is an increasing amount of evidence suggesting plastic changes in corticomotor areas can largely affect skill acquisition (Jensen et al. 2005). Proprioception, defined as awareness or sense of body spatial positions and segment placements, is information arising from sensory receptor systems (Ashton-Miller et al. 2001; Limanowski & Blankenburg 2016). Proprioceptive information about the surrounding environment and its interaction with accurate limb movements and fixation after perturbations is carried and processed in higher cortical levels (Ashton-Miller et al. 2001; Han et al. 2016). With proprioception, vision regulates and integrates multisensory information about body representations (Limanowski & Blankenburg 2016). Visual feedback is the most important input on proprioception, which is seen in change of somatosensory processing alteration after transient visual deprivation (Brodoehl et al. 2015).

The motor cortex continuously receives somaesthetic information, which can enrich and affect motor performance (Nudo et al. 2000; Veldman et al. 2015) As the corticospinal tract is able to adapt in response to training, skill learning induced changes can appear through anatomical and physiological adaptations that might induce representation organization and excitability changes (Adkins et al. 2006; Perez et al. 2004). Acute changes are performance related and observed after the training session, which relates to activation refinements e.g. inhibitory or synaptic efficacy alterations. (Jacobs & Donoghue 1991; Kleim et al. 2004). A change between inhibitory and excitatory mechanisms' balance and strengthening of already existing synapses are thought to represent relatively rapid plasticity processes (Hallett 2001; Rosenkranz et al. 2007b). Such shortly occurring mechanisms can be thought to represent short-term plasticity.

Skill training dependent changes in humans' intracortical circuits can be measured with specific intensities and intervals of magnetic stimulation that can be applied through transcranial (TMS) (Perez et al. 2004; Rothwell et al. 2009). The TMS method is based on motor unit excitation after stimulating axon cell bodies that possess specific thresholds (Rossini et al. 2015). Motor imagery activates neural areas in cortical and subcortical areas that relates to learning. With different emphasis in imaginary training attentional focus, there are specific neural activations to the relation of body and surroundings. The imaginary training varieties can cause different corticospinal activity of areas. It is thought that motor imagery affects motor skill acquisition through common neural substrates with actual task execution. (Munzert et al. 2009.)

The aim of the present study was to investigate transient visual deprivation on motor skill learning and arising proprioceptive alterations. Vision is thought as dominant sense in skill learning and taking it transiently off might alter learning adaptability and feedback processing. Transient visual deprivation is in relation with proprioceptive processing, which is an important aspect in motor skill learning. The study aimed to the investigation of proprioception alterations due to transient alterations of visual sense during skill learning. One of the main field of interest in the present study was to assess motor skill learning and its induced corticospinal tract excitability changes.

2 LITERATURE REVIEW

2.1 Human Nervous System

The human nervous system is composed of hundreds of billions of neurons and tens of thousands of inter-neuronal connections (Amaral 2000, 335). The nervous system is a fine structured complex and important pathway of information. The human nervous system contains two distinct parts, the central (CNS) and peripheral nervous system. The CNS is comprised of the brain and the spinal cord, while the peripheral nervous system consists of ganglia structures and peripheral nerves. Together, these systems provide sensory information about the environment, evaluation process of significant information about the surroundings. It also provides task-dependent behavioural responses. (Amaral 2000, 335.)

2.1.1 Central Nervous System

There are seven major parts in the CNS (Amaral 2000, 319). These are divided into the spinal cord and six parts of the brain. The latter includes the medulla, pons, cerebellum, midbrain, diencephalon, and telencephalon (fig. 1). The spinal cord, thought to be the simplest part of the CNS, is the most caudal part. The spinal cord comes down from the base of the skull to the vertebra of the lumbar region. The spinal cord receives information from different parts of the human. These parts are e.g. skin, muscles, and joints. Motor neurons that are responsible for voluntary and reflex movements are located in the spinal cord. There are white and grey matter in the spinal cord. Grey matter is formed from nerve cell bodies and is found in ventral and dorsal horns of the spinal cord. Information from peripheral structures are transmitted through sensory neurons in the dorsal horn. Ventral horn consists more of motor neurons acting upon skeletal muscles. White matter consists of myelinated axons that form these longitudinal ascending and descending paths of the CNS. These tracts relay sensory information to the brain and motor and modulatory commands from the brain. (Amaral 2000, 319-320.)

Nerve cells in the spinal cord that carry information from sensory receptors and muscles are bundled in 31 pairs that create the spinal nerves (Amaral 2000, 319). The spinal cord has two roots which locates the dorsal and ventral aspect of the cord. Roots on the dorsal side carry sensory information from the skin, muscles, organs, and other internal tissue to the spinal cord. Information that is conveyed from the spinal cord goes through motor neurons axon bundles in the ventral roots. These neurons innervate structures such as muscles. Motor neurons in the ventral root are defined as the final common pathway since they are the final link between neural information and muscle contraction. (Amaral 2000, 319-320.)

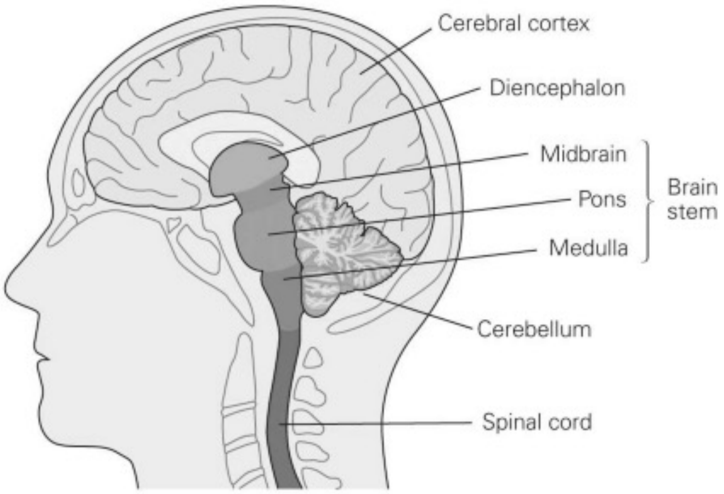

FIGURE 1. Seven major anatomical structures of the central nervous system (Amaral 2000, 320).

There are also important structures that are important when clarifying the function and anatomy of the CNS (Amaral 2000, 320). The medulla, pons, and midbrain together form the brain stem (fig. 1). The brain stem continues to the rostral aspect from the spinal cord and it contains clusters of nerve cells which have an impact on multiple motor and sensory systems. There are 12 cranial nerves functionally pairing with 31 spinal nerves that carry sensory input and motor output into the brain stem. (Amaral 2000, 320.) For example, sensory information about balance is important in training and it also affects proprioception (Amaral 2000, 320; Han et al. 2016). Neurons that form descending and ascending pathways relays sensory and motor information between the brain stem and other CNS divisions. Distributed through the brain stem there is the reticular formation, which controls arousal of specific organisms. This neuronal network receives a summary of sensory information, which spreads through the spinal cord. The medulla is mostly regulates blood pressure and respiration regulation, the pons takes part in controlling information and relaying of movement and sensations and the midbrain affects multiple structures via its linkages, e.g. part of basal ganglia, which controls voluntary movements. When thinking about skill training and training overall, vision is an important factor and the midbrain has multiple connections to structures that control ocular muscles of the eye. (Amaral 2000, 320-323.)

The cerebellum is also a part of the CNS (fig. 1) (Amaral 2000, 322). Lying next to the pons, this complex neuronal subdivision consists of a greater number of neurons than any other area of the brain. The spinal cord receives sensory information and the cerebral cortex brings motor information to the cerebellum. The cerebellum also receives information from the vestibular system, which controls balance and posture, important factors of skill learning. Also, fine motor coordination movement is regulated via the cerebellum. The diencephalon (fig. 1), a structure that lies in the middle of the brain, contains the thalamus and hypothalamus. The thalamus is the structure responsible for transferring multiple sensory information to sensory processing areas from peripheral receptors. The thalamus has a great modulatory role in sensory information relay by deciding if sensory information should reach neocortical conscious awareness. Motor information is partly integrated by the thalamus by transmitting the information from the cerebellum and the basal ganglia to other movement-related specific cortical regions. Ventral from thalamus lies hypothalamus. This complex brain area regulates multiple essential processes such as homeostasis and reproduction. With broad afferent and efferent connections, which reaches effectively to all regions of the central nervous system, the hypothalamus has a great effect on motor behaviour. (Amaral 2000, 322.)

The last of the seven distinct divisions of the CNS is the largest part, the cerebrum, also known as telencephalon (Amaral 2000, 322). Telencephalon is divided into two cerebral hemispheres. This area includes the cerebral cortex and the white matter underlying it, the basal ganglia, the amygdala, and the hippocampal formation. The basic processes that are regulated in the cerebral hemispheres are motor functions, cognitive processes, and perceptual operations, including memory and emotion. The corpus callosum is an interconnective structure between the hemispheres. It links the similar areas of the hemispheres via large commissural fibers. The amygdala controls social behaviour, emotion expression, memory functions in the hippocampus and fine movements by the basal ganglia. (Amaral 2000, 322-323.)

The Motor cortex as part of the cerebral cortex is highly associated with learning and cognition (Sanes & Donoghue 2000). Areas of the motor cortex differ respect to function. Somatotopic areas in the primary motor cortex control major body segments, like arms, legs, or the face. As a result of extensive connectional organization and synaptic capacity, the motor cortex has remarkably plastic capabilities. Synaptic strength changes are due to activity properties. (Sanes & Donoghue 2000.) A better insight into the structural organization of these cortical areas can be seen in figure 2 according to Penfield & Rasmussen (1950) as presented by Gramfort (2009).

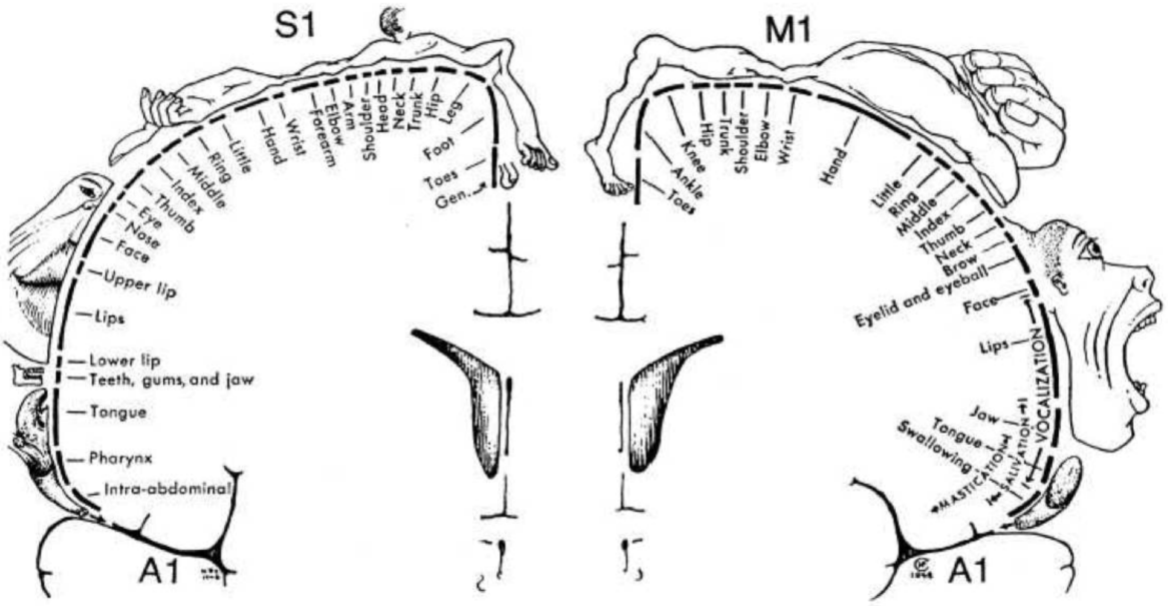

FIGURE 2. Primary sensory (P1) and primary motor (M1) cortical maps and representation areas according to Penfield & Rasmussen (1950) in the work of Gramfort (2009). (Gramfort 2009.)

The cortical area is highly connected via synapses to spinal motor neurons (Avela & Gruber 2011). Each spinal neuron gets information from cortical motor neurons. The pathway from pyramidal cells in the motor cortex is monosynaptic to spinal motoneurons. This organization affords human control over accurate complex movements. Force, accuracy, angular components, muscle tension, and movement sequences are controlled through this complicated arrangement. (Avela & Gruber 2011.) Central nervous system subdivions are functionally connected but anatomically distant from each other. These structural features are important when plastic functional changes or behavioural improvements are assessed. (Bachtiar et al. 2018.)

The motor cortex has a layered structure, with excitatory and inhibitory modulations found at different layers (Avela & Gruber 2011). Layers three and four are inhibitory layers containing Basket and Stellate cells, specific inhibitory interneurons. Small excitatory pyramidal neurons are in layers two and three. Their horizontal orientation is because of their dendrites. To activate these inhibitory and excitatory neurons there are specific neurotransmitters. Gamma-aminobutyric acid (GABA) acts as an inhibitory transmitter and glutamate as an excitatory transmitter. (Avela & Gruber 2011.) In the motor cortex, there is the topography of functional subregions (fig. 2) (Sanes & Donoghue 2000). Mostly behavioural flexibility of mammals is connected with the cerebral cortex. This implicates motor cortical circuitry and its abilities to modify architectural features. This indicates that these functions of these areas are part of the normal cortices’ expanded representation. (Sanes & Donoghue 2000.) Pyramidal tract neurons convey signal to the spinal cord and supraspinal and subcortical targets, which include brainstem, striatum, and thalamus (Canedo 1997).

2.1.2 Peripheral Nervous System

The peripheral nervous system is in charge of information mediation to CNS and carrying the brain and the spinal cord created commands into effect (Amaral 2000, 335). While the brain processes the information from external and internal environments, the peripheral nervous system possesses a great role in an organization of this information stream. Even though the peripheral nervous system is a separate structure from the anatomical aspect but from a functional point of view they both work in collaboration. (Amaral 2000, 335.) The peripheral nervous system holds an important key factor of myelin, which is formed from Schwann cells (Chen et al. 2015).

The two parts that the peripheral nervous system is divided into two parts, somatic and autonomic sections (Amaral 2000, 335). The somatic, or voluntary, nervous system receives sensory information from muscles, joints, and skin. Muscle and limb positions, pressure sensations and body surface senses are collected by sensory receptors and carried to the central nervous system. The autonomic part of the peripheral nervous system regulates smooth muscles, exocrine glands, and viscera systems. These include sympathetic, parasympathetic and enteric systems. The sympathetic system acts in response to stress, the parasympathetic for body homeostasis and recharge, and the enteric system is in control of the function of gastric smooth muscles. (Amaral 2000, 335.)

2.2 Plasticity of central nervous system

Plasticity is considered to be alterations and adaptive changes in neural networks due to specific types of training (Adkins et al. 2006). Brain plasticity can be considered as the neural ability to remember, learn and repair. Rapid plasticity changes can be seen in addition to long-lasting plastic processes. (Hallett 2000.) How these plasticity changes happen and what alters them is another question. Behavioural pattern changes are also one possible way to create changes in cortical regions (Hallett 2000). In addition to cortical plasticity changes, there are also levels of plasticity in the corticospinal region. The structural and functional response alterations can be measured by comparing different modes of motor training. The method of motor training dictates the specificity of the plasticity. Motor cortex synaptogenesis, synaptic potentiation, and areal representation reorganization are associated with skill training. Contrarily, endurance training is connected more with angiogenesis and strength training with spinal level neuronal excitability changes. All types of training influence task-dependent spinal reflexes. (Adkins et al. 2006.) Further, the specific reorganization of the motor cortex depends on acute or chronic plasticity (Sanes & Donoghue 2000).

The motor cortex and the spinal cord have a remarkable ability to adapt in response to training (Adkins et al. 2006). The specific type of motor training affects the structures and functions that are altered. As stated earlier, the motor cortex is a locus of many plasticity effects. Skill training is mainly associated with the motor cortex plasticity, while endurance and strength training are more linked to spinal and vascular alterations. (Adkins et al. 2006.) Specific behavioural and neural signals modulate and drive plasticity dependant effects in CNS (Plowman & Kleim 2010). These signals can be extrinsic or intrinsic. Extrinsic plasticity modulator signals include motor learning and recall, external stimulation such as electrical stimulation and pharmacological influencers. Intrinsic factors are borne by the individual. These include development levels, age, gender, genetics, and injury-related attributes like time and severity. These signals create an influence on plasticity capacity and its efficacy. (Plowman & Kleim 2010.)

2.2.1 Synaptogenesis

Skill training is largely associated with synaptogenesis, synaptic potentiation and movement representation area reorganization in the motor cortex and synaptogenesis is thought to represent later phase of motor skill learning (Adkins et al. 2006; Rosenkranz 2007b). Learning alters synaptogenesis and synapse elimination e.g. through myelination mechanisms (Fields 2015). Cullen & Young (2016) mentions a strong relation between astrocytes, a specific glia cell, and TMS mediated synaptic efficacy. They clarify that astrocytes notices the TMS derived increased neuronal firing and as a consequence synaptic glutamate uptake is maintained. Also, glia cells might act as cellular effectors to TMS, since they respond to created electrical activity. As a result, TMS activated glia cells regulates central nervous system activity. (Cullen & Young 2016.) While synaptogenesis is an important factor in learning and memory formation, the biochemical basis underlying it is still yet to be completely clarified (Nelson & Alkon 2015). Specific intracellular pathway signalling can mediate synaptogenesis. Synaptogenesis maintains an important role in increasing the number of synapses. (Fields 2015.)

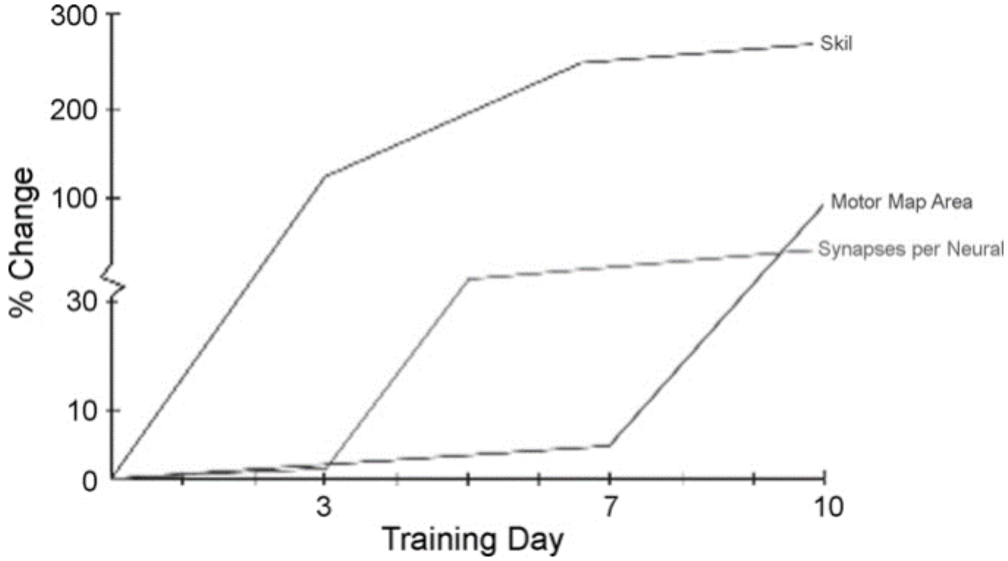

FIGURE 3. Illustration from skill training induced structural motor cortical plasticity in temporal scale (Plowman & Kleim 2010).

Specific synaptic activity can also modify synapse stabilization and maturation processes (Fields 2015). One underlying mechanism of synaptogenesis lies in intracellular proteins. The proteins mediate cytoarchitectural and neuronal connectivity changes (Fields 2015). Plowman & Kleim (2010) presents an illustration (fig. 3) from important plastic changes in temporal cascade form. The changes include synapse formation, synaptic reorganization, synaptogenesis, and motor map reorganization. (Plowman & Kleim 2010.) Motor training can alter the plasticity effects of synapses by promoting inhibitory and excitatory synapses (Kida et al. 2016). Besides, cortical synapse number adaptations are engaged to the late phase of learning due reorganization of the motor cortex area. (Kleim et al. 2004.) When practice is continued, synaptic connectivity by synaptogenesis is more in charge of enhanced recruitment at corticospinal and intracortical levels (Rosenkranz et al. 2007b). To perform complex task movements, changes in neural connections between these formations are created. These changes can be explained by an alteration in the number of synapses at the cortical level. Also, the strength of synapses and movement representation topography alterations are explanatory factors. (Adkins et al. 2006.) Skill learning may enhance neurophysiological features in the motor cortex including synaptic plasticity and synaptogenesis is thought to represent a long-term motor learning (Rosenkranz et al. 2007a; Rosenkranz et al. 2007b).

2.2.2 Synaptic Connections

Plastic changes can occur uniquely in presynaptic forms at a synaptic level (Ohura & Kamiya 2016). Different synaptic changes happen at the cellular level of plasticity and learning (Fields 2015). Synaptic connections are broken down and formed through neuronal functions and their plastic modifications. The connections are strengthened with specific arriving input and postsynaptic neuronal action potential firing relation. (Fields 2015.) Kempter et al. (1999) present the well-known Hebbian rule of learning. This specific asymmetric learning window of presynaptic and postsynaptic spikes models these neuronal connections (Kempter et al. 1999). When synaptic input arrives after postsynaptic neuron fires, synapses weaken. (Fields 2015.)

Training can alter motor cortical connectivity by enhancing it (Moscatelli et al. 2016). Motor cortex intrinsic synaptic circuitry studies have revealed that there does happen functional organization changes (Keller 1993). Usually, inhibitory plasticity connection receptors in the cortical regions act as GABAergic and excitatory connections utilize glutamate. These receptors have a role in temporal coordination for executing complex movement patterns. Acquiring new motor skills these connection activities are involved in creating representation area adaptions. While motor cortex specific structures own specific muscular maps containing corticospinal cells, they also facilitate synergists and reciprocal inhibition of antagonists via these cells. (Keller 1993.) These could be thought of as an essential part of skill training and performance of skilled motor movements. These neural organizations are part of skill learning adaptations, when their connectivity may change as a result of movement sequence refinement (Monfils et al. 2005).

There are suggestions, that in a rapid time course existing synaptic connections change the effectiveness rather than synaptogenesis occurs (Jacobs & Donoghue 1991). These might indicate that inhibitory mechanisms suppress specific muscle cortical projections at a neutral state of activity. To be compared, motor skill training might take out inhibition and combined with TMS-induced activation of neuronal connections, extra functional connections might occur. (Perez et al. 2004.)

2.2.3 Neurogenesis

Altman & Das (1965) present new neuronal formulation at the brain region as neurogenesis which affects learning and memory. (Kempermann et al. 2018). Neurogenesis occurs throughout life, and it can generally be described as the overall formation of new neurons (Ihunwo et al. 2016). Neurogenesis is thought not to be a part of the main supporters of cognitive performance enhancement (Kerr et al. 2010). Neurogenesis is a complicated context. It still is an important part of visual and spatial memory adjustment in the big picture. One important factor to remember is that the neurogenesis' role is enhanced only after the newly formed neurons are incorporated into the existing network. After forming, recently proliferated neurons are not yet ready to function and to be merged into existing networks. (Kerr et al. 2010.) It might take somewhat 4 weeks that newly formed neurons are integrated into the existing circuitry (Kee et al. 2007). Angiogenesis is more involved with memory formation than neurogenesis-related newly formed neurons (Kerr et al. 2010). According to Cullen & Young (2016), TMS is thought to link with neurogenesis in hippocampal level and they present an overall thought that TMS stimulation methods enhances neurogenesis via stem cells.

Compared to rodents, there are four times more neuronal generation happening throughout life (Ihunwo et al. 2016). Adult neurogenesis has risen a topic for cognitive enhancement and therapeutic issues. (Ihunwo et al. 2016.) Neurogenesis has been increased in the cell proliferation level with mice. This was when they had an unrestricted running possibility. Enriched environment and voluntary physical activity have an effect on cell production in the dentate gyrus. Mice research indicates that in the hippocampal level, voluntary exercise enhances cell proliferation, neuronal differentiation, and survival. (Van Praag et al. 1999.) To conclude from a functional aspect, neurogenesis is not obligatory for learning. On the other hand, it has more to do with the functionality of a more advanced level. Adult neurogenesis seems to be limited to striatum and hippocampus. (Kempermann et al. 2018.)

2.2.4 Reorganization

The motor cortex is anatomically and physiologically very well suited structure to adapt and perform skilled movements (Monfils et al. 2005). Motor skills produce the central nervous system to adapt within motor areas (Monfils et al. 2005). The motor cortex can adapt to long-lasting and rapid reorganization (Sanes & Donoghue 2000). Cortical reorganization is thought to happen in later phase of motor skill learning (Rosenkranz 2007b). It is argued, that the motor cortex is the foremost significant structure for skill training performance (Kleim et al. 2004). Still, it is not completely known how and wherein the brain skill performances are encoded. The motor cortex possesses motor maps and representation areas that own capacity to change and adapt to human motor learning. Changes that happen in the motor cortex are specific to the training type. Reorganization of motor movement maps can happen as areal expansion and or representation increase. (Kleim et al. 2004.) Nielsen & Cohen (2008) conclude that after a couple of minutes of voluntary activation in the muscular level is capable to expand the representation area. TMS, when applied to different muscle stimulation sites with different coil orientations, is able to map brain functions and cortical regions' excitability (Rossini et al. 2015). Plastic changes can affect the motor cortex's topography and muscle representation areas. This plastic reorganization is possible in the motor cortex specific to different body parts. Between separate body parts representation areas, there are some overlapping even though they are generally separate. (Rossini et al. 2015.)

The changes that skill training may induce are for example topography changes of movement representations and cortical synaptic strength and number alterations (Adkins et al. 2006). Motor skill training changes the movement representations organization by increasing the task-specific muscle area and excitability (Perez et al. 2004). Kleim et al. (2004) present in their article that motor map reorganization and synaptogenesis are shown to happen mainly with time. Skill learning does induce both reorganization and synaptogenesis. These mechanisms require time. Motor map reorganization is usually preceded by synaptogenesis in this later phase of skill learning in localized motor cortex regions. Kleim et al. (2004) suggest that these plastic changes act more as a consolidation of motor skills in the late stage of learning. The neural structures of the motor cortex possess body musculature somatotropic representations (Keller 1993).

Elsayed et al. (2016) present reorganization as a neuronal response. There is a specific neural structure that holds two circuits and they own different properties. They point out that responses in preparatory subspace relates to movement subspace response. This might indicate an estimation of performance strategy. (Elsayed et al. 2016.) Skill training is highly connected with neural circuitry reorganization at the motor cortex level. (Adkins et al. 2006.) Important aspects of plasticity are the mechanisms underlying the impulse propagation. This might be an important form of neural circuit plasticity representation (Fields 2015).

Neurons are modulated with the performance of new motor sequences (Lu & Ashe 2015). It is suggested that the motor cortex possesses a sequential motor skills behaviour characteristic rather than a single successive movement-related one. Memorized knowledge is said to be involved with learning. This knowledge is affecting efficiently on complex skills take on. This sequence-related activity can be reorganized in the motor cortex areas. Reorganization as a dynamic functional change of plasticity affects largely on a network of separate brain areas and even in muscle spindle level. (Lu & Ashe 2015.)

There is evidence found with electrical stimulation, which indicates rapid and long-lasting reorganization of central nervous system structures (Sanes & Donoghue 2000). This was seen with nerve transection leading to functional loss of the nerve of interest innervating areas. Context related activity patterns and resulted exposure can alter LTP mechanisms and reorganization of representation areas in motor cortex via adjustments of synaptic efficacy. (Sanes & Donoghue 2000.) Single training sessions can induce rapid improvements in performance. This improvement can happen by activation change in striatum and cerebellum. Long term, slower phase of adaptations in the performance process happen after multiple training sessions. The motor cortex is more involved with longer time required later phase of learning. This could mean that motor map reorganization happens more during the late phase. (Kleim et al. 2004.)

2.2.5 LTP and LTD

Motor skill learning can adapt via different physiological processes (Rosenkranz et al. 2007b). There are stages of learning that are time-specific. Fast learning can be consolidated during the next couple of hours after practice session. (Rosenkranz et al. 2007b.) LTP represents a long-term potentiation and LTD long-term depression as mechanisms of synaptic plasticity (Kronberg et al. 2017). LTD is more associated with tetanic stimulation. Also, postsynaptic depolarization below the LTP induction threshold induces LTD. It is crucial to notice that the excitability level underlying stimulated neurons matters when producing plasticity effects. Synaptic plasticity being LTP or LTD type depends on these mechanisms. (Ziemann et al. 2008.)

There are multiple timeframes underlying LTP-like mechanisms. After induction, approximately half an hour to six hours lasting potentiation is called short-term potentiation of LTP. Couple hours lasting after its induction LTP effect is called early phase of LTP. LTP effect that is sensitive to protein synthesis is referred late phase LTP and it can last over 24 hours. These mechanisms of LTP is expressed through synaptic plasticity with specific pre and post synaptic processes. (Kandel 2000; Lauri et al. 2007.) LTP plasticity effects can be measured with 30-60 min paired associative stimulation type TMS (Stefan et al. 2000). LTP-like plasticity can underlie early motor skill learning (Rosenkranz et al. 2007b).

It is suggested that early motor learning can enhance LTP-like plasticity at existing synapses (Rosenkranz et al. 2007b). Rosenkranz et al. (2007b) study shows that single session training enhances plastic changes in different ways than five-day training. One session included two similar 4 minutes lasting periods of motor movements with 4 minutes of resting in-between periods. Improvement in single training session is thought to unmask and improve the efficacy of existing connections by LTP-like plasticity while five-day training induces synaptogenesis. These mechanisms can be measured with paired associative cortical stimulation and specific interstimulus interval. (Rosenkranz et al. 2007b.) In addition, Cantarero et al. (2013) present that LTP-like plasticity is an evident part of the retention and acquisition of learning. Although the magnitude of LTP-like plasticity occlusion relates to motor task performance. It seems, that depotentiation can impair motor performance and skill retention. (Cantarero et al. 2013.)

Inhibition is seen as an essential part of LTP-like plasticity effects. This inhibition acting as a precursor is necessary, but it is known that aerobic exercise enhances the LTP-like plasticity induction. (Singh et al. 2014.) Plasticity changes in a short period have also been observed to include structural reorganization involving gray and white matter (Dayan & Cohen 2011).

2.2.6 Excitability Changes

There is evidence of an acute increase in the input-output curve indicating excitability changes at cortical level after 32 min of motor skill training. These changes were not found at passive or non-training subjects in the study of Perez et al. (2004). Increased MEP after skill training indicates changes at a cortical level instead of corticospinal. Also, inhibition levels were found to decrease after skill training. It is thought that the degree of difficulty plays a major role in the appearance of plastic changes. Compared to skill training, non-skill and passive training is associated with a low rate of excitability changes. This skill training-induced changes may have a positive effect on recovery (Perez et al. 2004.)

Excitability can be called as responsiveness to stimulation (Kobayashi & Pascual-Leone 2003). The cortex of the brain has specific excitability and interaction between cortical regions. TMS is a way to study this responsiveness to stimulation. (Kobayashi & Pascual-Leone 2003.) Increases in corticomotor excitability are also possible (Nielsen & Cohen 2008). This muscular excitability might reflect the unmasking of already existing projections of the muscle in the corticospinal level (Nielsen & Cohen 2008). Classen et al. (1998) present a thought that repeated movements can reinforce connections. This means that the connections weaken if no movement is executed. The unmasking might be related to existing cortical projection inhibitory mechanisms that are removed by training (Perez et al. 2004). This unmasking or inhibitory removal could be connected to cortical representation expansion. (Perez et al. 2004.) Improvements already after a single training session can alter the recruitment of corticospinal output and change intracortical inhibition levels affecting the performance (Rosenkranz et al. 2007b).

A one session of ankle motor skill training can induce plasticity changes at the corticospinal level. Decreases in intracortical inhibition may explain the increases in intracortical circuits. Improvements in ankle motor performance after skill training may be due to plastic changes. In the study of Perez et al. (2004) motor skill training of the ankle induced cortical excitability changes at neurons with higher threshold to TMS. Changes at higher threshold neurons most likely means expansion of the representation area of the muscle used as an agonist in skill training. The decrease in inhibition may indirectly contribute to cortical plasticity. (Perez et al. 2004.)

2.2.7 Metabolic Changes

Angiogenesis is thought of as a reliant part of memory formation (Kerr et al. 2010). Exercise-induced improvements in angiogenesis explain the benefits claimed in learning and memory functions. The vascular gain and plasticity are crucial variables in learning. (Kerr et al. 2010.) Blood flow of cortical neural tissue can be altered with endurance training rather than skill training (Adkins et al. 2006). The primary effect of endurance training focuses on cerebrovascular changes. Exercise training-induced angiogenesis and blood flow increase might be due increase in metabolic level demands of cortical neurons. These changes happen in motor cortical level, but the frontal cortex and other subcortical areas have been found untouchable with these alterations. This means that induced alterations are specified to the areas that training activates. (Swain et al. 2003.) Some rapid changes can adapt as a response to motor training. These include viscosity change such as water content change (Sanes & Donoghue 2000). This acute or rapid adaptation can occur after a few repetitions (Sanes & Donoghue 2000).

Skill training affects the brain-derived neurotrophic factor (BDNF) levels and tyrosine kinase receptors (Adkins et al. 2006). Compared to that, endurance and resistance training might act more as nutritive support. This is a result of the neural environment adapting through blood flow, increased vasculature or growth factors. Only skill training is thought to have effective and significant changes in cortical circuitry. (Adkins et al. 2006.)

These plastic cellular adaptations of the nervous system can reach beyond the synapse level (Fields 2015). Conduction velocity can be modified through myelin changes. This changes the level of transmission of information through neural circuits. Conduction velocity changes indicate alterations of the myelination process. Changes during learning happen also in white matter. Axonal propagation can change the speeding of neurotransmission. (Fields 2015.) Also, membrane potentials can hold plastic effects responding to training. According to Kida et al. (2016) resting membrane potentials and threshold can have training dependent plasticity effects in specific II/III neurons in M1. (Kida et al. 2016.)

2.2.8 Spinal Cord Plasticity

The human spinal cord is able to adapt to a specific kind of action (Christiansen et al. 2017). Neural circuitries of the spinal cord are adaptable structure and plastic changes can be caused by supraspinal input. Also, afferent input to the spinal cord can change the circuitry. Actions that are able to alter these circuitries are e.g. learning, immobilization, injury, and neural rehabilitation. The spinal cord is highly dependable on sensory and supraspinal input. This means that functional integration alters the spinal networks. Plastic changes in spinal level might happen because of descending input, afferent input or sensory supraspinal integration. This might indicate task-specificity. Spinal level plasticity appears to happen in relation to cortical changes. This could be due to the fundamental thought that the brain and the spinal cord work together to generate and control movements. (Christiansen et al. 2017.)

Electrically induced H-reflex is an Ia-afferent driven reflex that reflects spinal level plasticity (Adkins et al. 2006). Changes in H-reflex reflect motoneuronal adaptations in firing threshold, reduced inhibition, increase in inhibitory synapses and reduced axon conductance. (Adkins et al. 2006). Although, a half an hour motor skill training session can increase MEP sizes in the tibialis anterior (TA) muscle cortical level. Motor skill training most likely can induce corticospinal control enhancement (Perez et al. 2004).

There are largely found evidence of presynaptic excitability change in sensory afferents and motoneurons (Perez et al. 2005). These structures and their plastic changes are essential for the reflex circuitry. Changes in reflex properties might be related to the process of motor learning. (Perez et al. 2005.) Perez et al. (2007) used co-contraction training that featured antagonistic ankle muscles. In their research, H-reflex measured from soleus muscle (SOL) was depressed. This might be because of an increase of Ia-afferent level presynaptic inhibition. They also found intracortical inhibition decreasing the excitability of corticospinal tract cells. Depression of H-reflex size happened after repetitions of co-contraction training that contained antagonistic muscles. Reflex pathways adapted and corticospinal excitability changed due to this type of training. (Perez et al. 2007.) Spinal cord reflexes can be altered with motor training, but the changes are highly dependent on task specificity of the training type behaviour (Adkins et al. 2006).

Through lifespan, the spinal cord can adapt specifically like brains do (Wolpaw 2007). The plasticity effects at the spinal level happen usually through neuronal and synaptic sites with different mechanisms. The plasticity of the spinal cord has a role in motor skill learning and acquisition. The spinal cord receives a descending input that induces plastic changes. This can lead to the spinal cord reflex pattern alterations which eventually helps to standardize locomotion in specialized skills like dancing. While H-reflex can be evoked electrically in primary afferent neurons, the spinal reflex pathway has a brain-created descending influence. This influence acts on motor neurons or afferent connections by changing the H-reflex size. (Wolpaw 2007.) Changes at the spinal level are thought to be paralleled with cortical level changes (Nielsen & Cohen 2008). The spinal level changes are thought to act through circuitry transmission changes. These changes regulate sensory feedback mechanisms and task performance. (Nielsen & Cohen 2008.)

2.3 Skill Training and Learning

Acquiring skills and adapting those in basic behaviour through experience is thought of as learning (Green & Bavelier 2008). These are important basics of survival, and humans have a unique capacity for learning. Green and Bavelier (2008) define skill training as a change in perceptual, cognitive, or motor performance improvement. This improvement is a result of specific timed training sessions. This training type can be weeks to months, but the adaptation effects depend on the type and time of training. Research distinguishes adaptations that occur after minutes of training, short fast stage learning, and slower stage that appears after hours and days of training sessions. This distinction is notable in both, perceptual and motor learning domains. (Green & Bavelier 2008.) When thinking about skill acquisition, there is increasing evidence that plastic changes in the motor cortex play a great role. (Jensen et al. 2005.)

Adkins et al. (2006) clarifies skill training as the acquisition of movement sequence combinations. Strength training is defined as resistance exercise increasing force capacity and endurance training referred to as an increase of capacity for continued motor performing. It is thought that different specific trainings are coded to dissimilar patterns. These patterns distinguish anatomical and neurophysiological plasticity mechanisms in the motor cortex and/or spinal level. (Adkins et al. 2006.) In addition, non-skill training or inactive passive motor training is thought to elicit none or only minor excitability changes (Lotze et al. 2003). Active training can lead to significant improvements in the performance of motor skill acquisition. Training, that does not include voluntary movement performance can elicit motor learning. (Lotze et al. 2003.) Conforto et al. (2002) suggested that motor performance can be influenced by somatosensory input. What underlies this is suggested to be sensorimotor cortical reorganization and subcortical structural modification. (Conforto et al. 2002.) Prolonged training done passively can alter cortical representation and primary sensorimotor cortex and supplementary motor areas (Carel et al. 2000). Furthermore, plastic changes in the primary sensorimotor cortex and supplementary motor areas can be induced with proprioceptive inputs done in chronic sequence. (Carel et al. 2000.)

Increases in strength levels can be explained by the enhanced contribution of training dependent corticospinal plasticity changes. However, the reasons behind the level of dominance in spinal or cortical level plasticity remains unclear. (Adkins et al. 2006.) Some strength training movements act as skill training because of complex or new movement patterns which can alter corticospinal tract like skill training does. Then it is possible that strength training via skill required components and improved coordination induces neural adaptations like movement representation reorganization in the cortical area. (Carroll et al. 2001.) Neuronal mechanics that underlie increases in neuronal drive in the early stage of strength training are still under construction. There are suggestions that the cortical drive plays a role in spinal motoneuronal level activation. (Aagaard et al. 2002a.)

2.3.1 Motor Control in Skilled Movements

Controlling movements, such as leg related balance and gait, are important factors of everyday life. These controlled movements are highly adaptable and are monitored by cortical control. (Beck et al. 2007.) Motor control is specific to the type of contraction. The performance of muscle contraction differs depending on the functional task and signals from the spinal cord (Duchateau & Enoka 2008). When muscle is shortening or lengthening, motor unit activity varies. Cortical output is different when comparing descending outputs of concentric and eccentric contractions. Cortical potentials linked to specific movements provide information about brain outputs. During lengthening contractions, the changes in the brain outputs indicate more brain-related involvements in the planning, preparations, and execution of movements compared to shortening contractions. It is also suggested that sensory processing is more present during lengthening contractions. (Duchateau & Enoka 2008.) Motor output is mediated presynaptic and postsynaptic sides of motor neurons (Duchateau & Enoka 2016).

When thinking about motor control, proprioceptive information plays a major role (Yavuz et al. 2018). The muscle spindle system is also a significant component of motor control due to sensory-motor organization. Part of the motor control acts through a muscle spindle system. This system transforms spindle sensing stretch movement through the muscle alpha motor neurons. (Yavuz et al. 2018.) If this activation would be excitatory, it requires an antagonist muscle to be relaxed (Sherrington 1913). If motor control is wished to be improved, training should be specific goal-oriented (Chong et al. 2001).

Basal ganglia play an important role in motor control (Visser & Bloem 2005). It is thought, that these structures have a meaningful role involving muscle tone, somatosensory integration, cognition, and behaviour. One important factor basal ganglia are involved in is an afferent information processing. It has an impact on postural control and body scheme organization. (Visser & Bloem 2005.) When comparing ankle muscles such as soleus (SOL) and TA, Lauber et al. (2018) found short-interval intracortical inhibition (SICI) and its task-specific modulation more pronounced at TA rather than SOL (Lauber et al. 2018). Intracortical inhibition is reported to be almost absent in levels, where TA is acting as an agonist. It is thought that in motor control allowed ballistic type movement creates high-level cortical drive. (Lauber et al. 2018.)

The role of motor control in learning can be thought of as cortical regions influencing the automaticity of movement system projections (Floyer-Lea & Matthews 2004). It is revealed that not only cortical or spinal structures affect singular but together in the simplest tasks we know (Petersen et al. 2003). This is backed up by Petersen et al. (2003) study, which mentions the corticospinal tract acting as an important contributor to walking. (Petersen et al. 2003.)

2.3.2 Impact of Vision on Motor Skill Training and Learning

Visual input has a meaningful effect on cortical plasticity (Leon-Sarmiento et al. 2005). Change in vision affects motor response. Visions effect can be measured by altering the light conditions. An example from this is measuring cortical potentials in eyes open and closed. There is evidence suggesting that motor evoked potentials changing when altering vision. This indicates visual input effecting on motor cortex activities in humans (fig. 4). (Leon-Sarmiento et al. 2005.) Vision can be thought of as having an impact on skill learning and motor movement success. Jensen et al. (2005) demonstrated that visuomotor skill acquisition correlates with increased corticospinal excitability.

There are studies done that support the idea of vision impacting on cortical excitability changes (Perez et al. 2004). The essential part affecting these changes are visual input and motor performance. Performance that requires visual impact on motor skill training modifies the activity of spatial neurons of the motor cortical level. (Perez et al. 2004.) Retention and learning new visuomotor skills reflect the visuospatial cues transforming to motor commands (Paz et al. 2003).

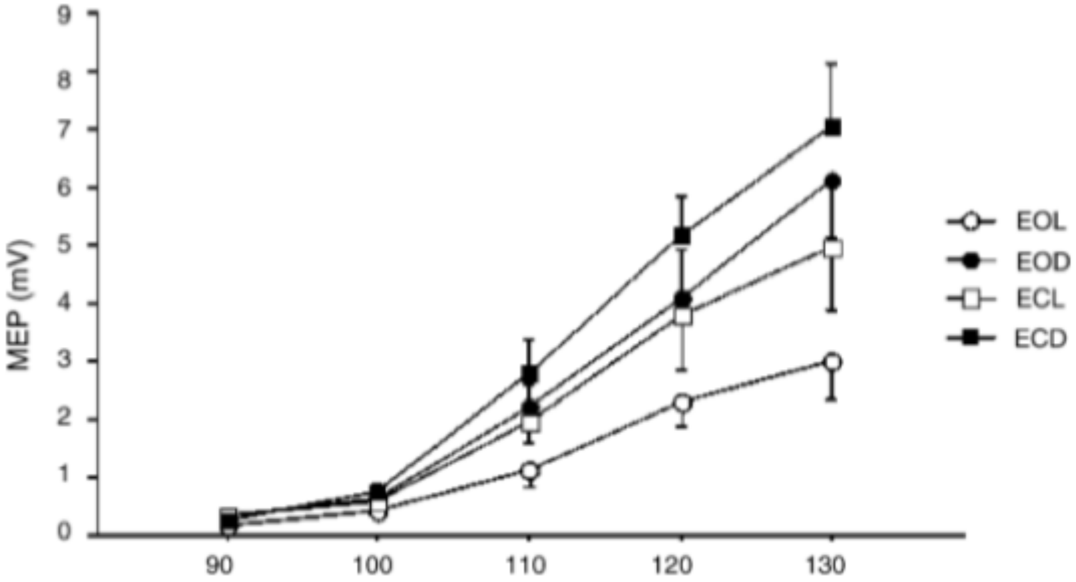

FIGURE 4. IO curve of five intensities in different conditions; light eyes open (EOL), light eyes close immediately (ECL), after 30 min of darkness eyes open (EOD) and closed (ECD) (Leon-Sarmiento et al. 2005).

Hirano et al. (2018) study used a visuomotor tracking task as motor training performed with ankle dorsiflexion and plantarflexion. They thought that new motor skill induces reorganization of the motor cortex. Reorganization patterns between subjects are highly individual and variable. Even though, there are the same motor training inducing these improvements. When active visual sense feedback is deprived, motor performance is guided through memory. Hirano et al. (2018) studied TA muscle with TMS. They researched visuomotor skill acquisition through memory-guided movements and learning induced plastic reorganization. They hypothesized that motor cortical plasticity is associated with improvements in movement control and strategy. The research found out that reorganization done with visually guided movements is associated with memory-guided control strategy. (Hirano et al. 2018.)

2.3.3 Sensorimotor Effect in Motor Skill Training and Learning

Mainly TMS has been used to assess training type-dependent acute plasticity changes in cortical areas (Beck et al. 2007). Special sensory-motor circuits can be induced by plasticity effects. (Beck et al. 2007.) It has been researched that sensory input has an effect on voluntary motor functions. The surrounding environment can serve feedback. This information is conveyed to sensory inputs to specify the process of motor learning. Without any or with reduced sensory information, motor functions decrease. (Veldman et al. 2015.) According to Nudo et al. (2000), the motor cortex interconnects somatosensory inputs continuously. Information is transferred to somatosensory feedback structures. This motor cortex neuron driven transfer proceeds via afferents. They conclude that it is widely unknown how motor commands are created in the motor cortex. It is also unknown how somaesthetic information is included in the creation. (Nudo et al. 2000.) It is thought that sensory feedback is enhanced on the side of normal feedback information. This might increase motor performance. This could be researched via somatosensory electrical stimulation in peripheral nerves. Enriched sensorimotor feedback could lead to increased activation in the primary sensory cortex. (Veldman et al. 2015.)

Sensory impacts on motor training have also been researched via the effects of music (Rosenkranz et al. 2007a). Musicians show greater finger representation area, functional, and structural changes in the sensorimotor cortex compared to non-musicians. These enriched somatosensory capabilities due to musical training enhances motor and sensory learning. (Rosenkranz et al. 2007a.) Sensorimotor training is also well used in rehabilitation and injury prevention. Sensorimotor training is a really effective way to gain proprioceptive affection to the neuromuscular system. This training helps to process proprioceptive information properly. (Gruber & Gollhofer 2004.)

2.4 Proprioception

The term proprioception refers to awareness of the body positions and body segment placements. Word proprioception dates back to the Latin word *(re)ceptus* and *propius* which means receiving and ownership. Usually, proprioception is measured with sensing segment position or joint angle changes in a situation where visual senses are excluded. (Ashton-Miller et al. 2001.) The brain combines different sensory information to the representation of body structure and position. Vision and proprioception has great effectivity on assessing limb position estimates and guiding actions. (Limanowski & Blankenburg 2016.) Sensory receptors that carry proprioceptive information includes four different afferent receptors. Areas that carry conscious proprioception are mesencephalic reticular formation, cerebellum, thalamic relay nuclei, and sensory cortex. These areas get the somatosensory information via dorsal column-medial lemniscal pathways of the spinal cord. Then some areas process subconscious proprioceptive information. These areas include cerebellum. The cerebellum is an important area to involve movement modulations and balance. Also, information from these systems is regulated via the spinocerebellar tract. (Ashton-Miller et al. 2001.)

When proprioception is researched, usually auditive and visual sensory inputs are blocked out. This does not test the proprioception in normal performance conditions in the real world. In everyday activities, the role of proprioceptive comes important when performing and fixing accurate limb movements to interact with the surrounding environment. These actions involve tasks as judgment of ankle inversion to correct balance perturbations. (Han et al. 2016.)

2.4.1 The Concept of Proprioception

Attention regulates and controls the memory building system. Learning is needed when adapting sequences of motor actions. Attention is a crucial reliant part of learning. When the learning process is being consolidated, attentional needs decrease. Reliant difference between learning of different systems are perceptual and motor concept. Motor memories require the real performance of movements. Attention has an improving effect on movement quality. (Stefan et al. 2004.)

Proprioception is based on mechanoreceptor feedback integration (Han et al. 2016). Most activities are associated with environmental components that guide movements. Sensory information behind neuroplasticity plays a crucial role in information processing in task-dependent movements. Promoted neural development source in task-specific actions is proprioception. According to Han et al. (2016) review, Charles Bell wrote that proprioception is thought of as a circle of nerves between the brain and muscles. The sense of the condition of the muscle to the brain comes from ventral nerve roots. This way, muscle sense is a concept based on two pathways. The afferent pathway circles from muscles to the brain and the efferent pathway conveys from the brain to muscles. The term proprioception can be sorted as a sense of joint position, and kinaesthesia then refers to conscious awareness of motion in the joint. It could be thought that proprioception is a broader concept and kinaesthesia is only submodality of proprioception. This concludes that proprioception can be thought of as a part of both movement and position sense in joints. This is strengthened by that both these senses in activities are always accompanied by each other. (Han et al. 2016.)

The information behind the term proprioception comes from various mechanoreceptors. The signals come within the nervous system, which ushers the physical senses of various organs. To clarify, sound waves contact eardrum and creates the sense of hearing. Vision is based on light affecting the retina of the eye. Neurons can transduce this electrical energy. This is how mechanoreceptors sense body movements to threshold. Human is capable of integrating these created signals to determine spatial movements and body segment positions. (Han et al. 2016.)

2.4.2 Visoproprioceptive Integration

When eyes are closed, EEG studies show a rise in alpha power. This was described Berger in the year of 1929, according to Ben-Simon et al. (2013). It is researched that alpha synchronization rises in demanding cognitive processes. These processes include spatial attention and working memory retention. Task difficulty relates to alpha rhythm synchronization. (Ben-Simon et al. 2013.) Visual feedback has a role in proprioceptive limb position representation. Neurons that have multimodal receptive fields in the posterior parietal cerebral cortex and the ventral premotor cortex, are in a great role in seeing and feeling limb positions. Visual and proprioceptive information about positions is coded in representations on posterior parietal and ventral premotor cortices. Both these fields are responsible for integrating the information into multisensory body representation. That makes proprioceptive information crucial to spatial outlining. It also makes visual feedback significant estimating the contribution of areal body representations. (Limanowski & Blankenburg 2016.)

It is well researched that visual feedback affects proprioceptive sensory systems (Brodoehl et al. 2015). Eyes are the dominant sensory system with humans. When the visual system gets blocked e.g. when eyes are closed, the normal visual dominance changes more into somatosensory information processing. This change between sense dominance can happen even when eyes are closed in complete darkness. The threshold of perception decreases when eyes are closed and as a consequence, fingers get more sensitive to the environment. Even in darkness, closing eyes a blood-oxygen-level-dependent (BOLD) activity increases in areas affecting visual processing and somatosensory information. Considering these circumstances, the act of eyes closure improves somatosensory perception because of altered processing mode. When eyes are open and vision enabled, brains work with thalamocortical networks. Eyes closure switches this to be a more non-visually dominated mode of processing. (Brodoehl et al. 2015.)

2.5 TMS in Measuring Brain Plasticity

Transcranial magnetic stimulation, abbreviated as TMS, is a non-invasive method to assess changes of neural network e.g. after skill learning (Perez et al. 2004). It was originally found to assess human corticospinal tract integrity (Reis et al. 2008). TMS measures humans intracortical circuits with a magnetic field induced through the scalp. TMS affects cortical neurons by activating their cortical outputs. These outputs can be measured from innervated contralateral muscles. Excitatory inputs of synapses in the motor cortex are stimulated via correct TMS intensity. (Rothwell et al. 2009.) Magnetic field usually created with about 1 ms square pulse of high-intensity brief TMS stimulus. The pulse is effective and it carries the electrical field through the scalp and skull to the brain matter. Neurons are depolarised and small action is shown in the contralateral target muscle. TMS mostly stimulates synaptic inputs of large axons in corticospinal neurones. Intracortical circuits are also affected due TMS. (Rothwell et al. 2009.)

TMS measurements have been evolved to protocols that measure excitatory and inhibitory interactions in cortical areas across both brain hemispheres (Reis et al. 2008). Motor control and neuroplastic changes can be measured with different applications of TMS. TMS is a tool to assess e.g. recovery functions. TMS is a valuable tool due to its ability to provide important information from the connectivity of separate neurological areas of the central nervous system. TMS can be used to measure the relationship between the anatomical configuration of brain regions and physiological processes. Pathways can alter due to training and TMS can provide information about changed connections and pathways between these structures and processes. (Reis et al. 2008.) TMS offers many available methods to assess brain plasticity in humans. These methods e.g. are single pulse stimulation, paired associative stimulation (PAS), repetitive transcranial stimulation (rTMS), theta burst stimulation and paired-pulse stimulation. (Hallett 2007; Reis et al. 2008; Chen & Udupa 2009.)

The motor cortex is a largely favoured area of research (Rossini et al. 2015). It has its well-established neurophysiology and conduction properties. The motor cortex possesses descending corticonuclear and corticospinal connections. Changes in relation to intervention and sampling can provide evidence for example through threshold, MEP amplitudes, cortical silent period durations, central motor conduction times and MEP recruitment curves. (Rossini et al. 2015.)

The method behind TMS is based on a coil of wire producing rapidly changing current emerging to magnetic field (Avela & Gruber 2011). The coil is placed over the scalp and the magnetic field generates an electric current in the brain depolarizing membranes of the neurons (Avela & Gruber 2011). Magnetic field is born when lines of flux pass perpendicularly through the motor cortex (fig. 5). This creates an electric field perpendicularly to the magnetic field. To the plane of the coil, current flows in parallel loops. The coil produces a focal maximal current at the intersection of the two components. This type of stimulation does not reach corticospinal neurons but it activates them through synaptic inputs. (Hallett 2000.) This TMS induced transient perturbation is selected via coil placement (Lin et al. 2010). The placement is crucial when assessing specific cortical regions. (Lin et al. 2010.) Neural depolarization results in excitatory or inhibitory potential in postsynaptic structures of cortical neurons (Avela & Gruber 2011).

TMS stimulates neuronal axons due to cell bodies tend to have a higher threshold and longer electrical time constant (Rossini et al. 2015). Axons are best stimulated and axonal orientation helps current flow parallel. Specific excitation of axonal nerves depends on threshold properties, orientation, and membrane attributes. It is thought, that corticospinal output has a correlation with white matter. This is due to its axons of corticocortical loop fibers that connect with corticospinal output. (Rossini et al. 2015.)

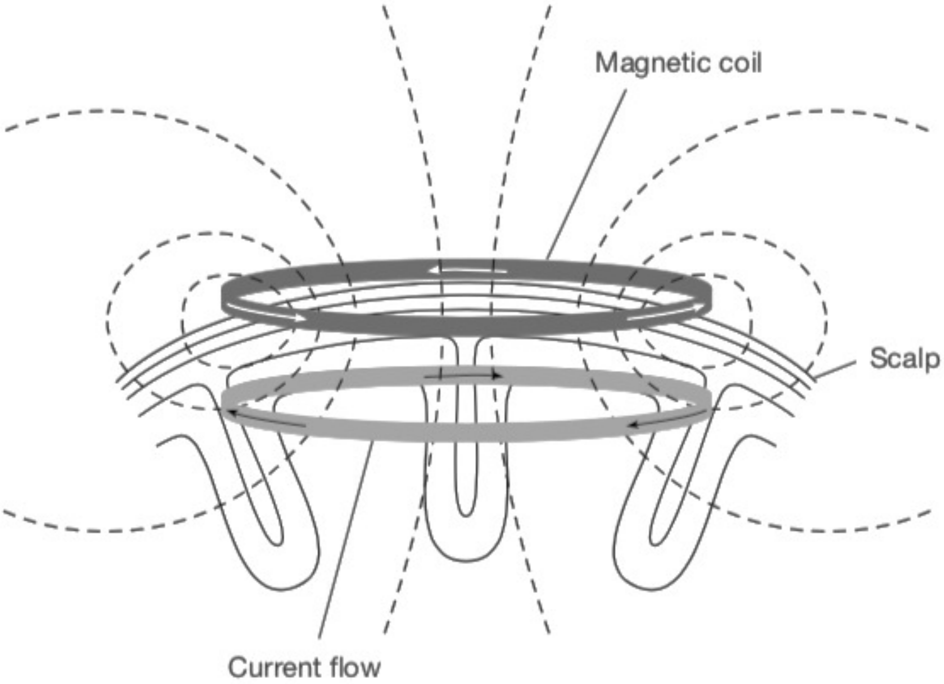

FIGURE 5. TMS coil produced current flux in cortical area (Hallett 2000).

The reason TMS evoked muscle potentials are shaped differently compared to peripheral nerve stimulated potentials is the underlying physiology (Groppa et al. 2012). In target muscles, TMS creates desynchronized motor unit excitation. There are multiple mechanisms contributing to this. These include the conduction velocity of peripheral motor axons, motoneuron pool features, and different time variations. Intrinsic fluctuations are lying under effecting on cortical and spinal level neural excitability. There are cancelation that is caused by desynchronized muscle activation explaining the MEP amplitude size compared to electrical stimulation evoked response. (Groppa et al. 2012.)

2.5.1 Single Pulse Stimulation

TMS single-pulse stimulation is safe and one of the most frequently used ways to study cortical excitability changes (Hallett 2000). It is a non-invasive method to stimulate the brain and measure changes in the motor cortex (Lopez-Alonso et al. 2015). Single-pulse TMS can depolarise measurable effects in neuronal level (Kobayashi & Pascual-Leone 2003).

For the past couple of decades, single-pulse stimulation has been often used as a corticomotor excitability research method (Sivaramakrishnan et al. 2016). The corticomotor area represents each optimal muscle stimulation sites. These optimal sites are referred to as ''motor hotspots''. They act as a place where TMS can elicit maximal responses of specific muscles. The largest responses are the largest MEPs. When studying temporal cortical changes, hotspot locations are important to assess. (Sivaramakrishnan et al. 2016.)

2.5.1.1 Motor Threshold

Motor threshold is thought to reflect the excitability of corticospinal neuronal membranes (Kobayashi & Pascual-Leone 2003). Also, these neurons are affected by interneurons. This membrane excitability reflects also the spinal cord neurons, neuromuscular junctions, and muscles. Motor threshold is measured with TMS from the scalp. TMS measures the activity of the pyramidal cells indirectly. (Kobayashi & Pascual-Leone 2003). Motor threshold is the level of needed intensity to create visible motor evoked potential. Stimulus intensity that creates this minimal visible MEP is motor threshold. (Chen et al. 1998.) Hallett (2000) describes the MEP threshold as a reflection of the central core neuronal excitability of the resting state muscle. This excitability arises from separate neurons that have local specific density. This motor evoked potential thresholds described plainly are membrane excitabilities. (Hallett 2000).

Pascual-Leone et al. (1995) article identifies motor threshold as the level that has the lowest intensity that evokes more than or equal five MEPs that has more or equal 50 μV peak-to-peak amplitude. Different types of training can alter motor threshold levels by lowering them from the training muscles. These training types include both physical and mental practices.

(Pascual-Leone et al. 1995.) Motor threshold also can be thought to be the intensity level to elicit visible MEPs that has peak-to-peak amplitude more than 50 µV in at least 50 % from the trials done successfully (Kobayashi & Pascual-Leone 2003).

Motor threshold that is measured in a total resting state of the target muscle is called the resting motor threshold (rMT) (Avela & Gruber 2011). This specifically reflects the global level of excitability in the corticospinal tract. It includes pyramidal cells in the cortical level, interneurons, and spinal motoneurons. Active motor threshold (aMT) is usually lower than rMT due to its slight voluntary contraction in target muscle (Avela & Gruber 2011.) When quantifying rMT, EMG should be completely absent (Rossini et al. 2015). The resting motor threshold is also described in Smith et al. (2011) article as reflecting membrane channel level and excitability features. These characteristics include cortico-cortical axons and excitatory synapses with neurons that have motor outputs. (Smith et al. 2011.)

Motor thresholds can detect different neural sections. Over 75 m/s velocity axons are called fast-conducting axons and slow-conducting axons tend to have velocity under 55 m/s (Kobayashi & Pascual-Leone 2003). With TMS, these different axons can be found with specific motor thresholds. This is due to the fact that fast-conducting axons have a lower threshold for direct waves and slow-conducting axons have lower threshold for indirect waves. TMS is able to excite cortical axons with high stimulation intensity. To sum up the meaning of the motor threshold, it gives us information about presynaptic circled efficacy in neuronal circuits from cortical areas to muscles. (Kobayashi & Pascual-Leone 2003.) When motor threshold is measured, physiological noise cannot be eliminated but physiological variables can. This means keeping coil position as constant as possible, its orientation identical, muscular state the same, arousal at the same level and environmental noise states minimal. (Rossini et al. 2015.)

2.5.1.2 Motor Evoked Potential

One way to exam corticospinal path excitability is to assess amplitudes of the motor evoked potentials, MEPs (Veldman et al. 2015). These can be induced via TMS. The change in measured MEP amplitude size stands for excitability changes in the corticospinal tract

(Veldman et al. 2015). MEP is objectively measured as the output of the motor cortex (Reis et al. 2008). Model of TA motor evoked potentials measured in the study of MacDonald et al. (2013) can be seen in figure 6. MEP also exhibits cortical, nerve roots, conduction and peripheral motor pathway circuits to the descending muscles (Kobayashi & Pascual-Leone 2003). MEP changes can also mirror abnormalities in the corticospinal pathway level. MEP size and latency depends on the subject being measured. There are interindividual and intraindividual differences. (Kobayashi & Pascual-Leone 2003.)

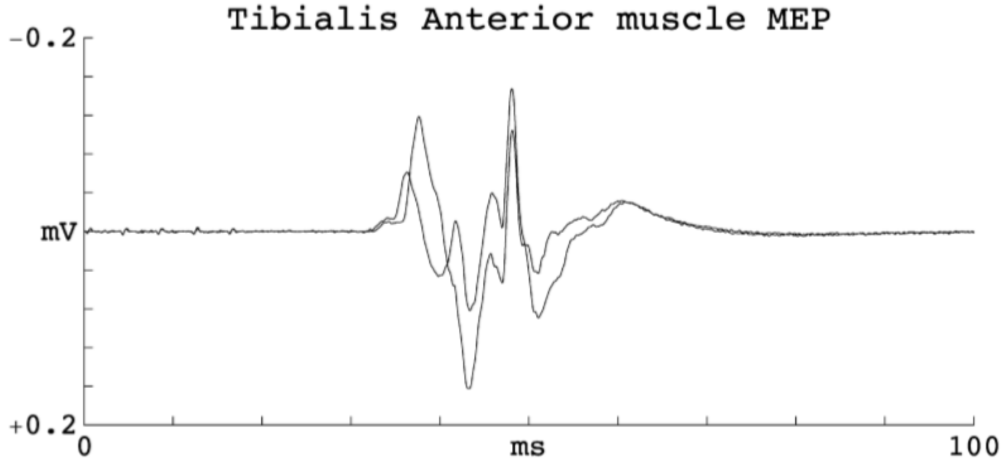

FIGURE 6. Two superimposed motor evoked potential measured from tibialis anterior (MacDonald et al. 2013).

MEP is measured with electromyographic recording electrodes placed the skin above the target muscle (Reis et al. 2008). MEP is elicited with suprathreshold TMS stimulation with the coil positioned on the target muscle representation area in the motor cortex. Conditioning the pulse intensity of TMS makes MEP modifying possible. (Reis et al. 2008.) Change in MEP size reflects changes in corticospinal, cortical or spinal excitability (Quartarone et al. 2004).

2.5.1.3 Input-Output Curve

Corticospinal excitability and neural plasticity can be represented as a change in the MEP recruitment curve (Chen et al. 1998). MEP recruitment curve in this context is, in other words, the input-output curve (I/O curve). MEP amplitudes that are created with increasing stimulus intensity assemblies as I/O curve. This curve reflects the corticospinal projections' strength. Strong corticospinal projections relate to lower motor threshold and a steeper I/O curve than muscles possessing weaker projections. (Chen et al. 1998.)

I/O curve is said to describe the growth of MEP amplitude size concerning stimulus intensity (Hallett 2000). I/O curve measurement includes other neurons than those in the core region activating at the MEP threshold. These I/O curve activating neurons possess a higher threshold to activate due to their intrinsic characteristics. These neurons have different properties e.g. they lie further from the magnetic stimulus activation centre and they have lesser excitability abilities. (Hallett 2000.)

I/O curve can indicate plastic changes (Cirillo et al. 2011). Visuomotor training is able to modify I/O curves measured in the first dorsal interosseous muscle. Increases in MEP amplitude sizes indicate corticospinal neuron activation abilities. (Cirillo et al. 2011.) Specific I/O curve components can provide information about the excitability of the corticospinal tract. Single-pulse TMS is able to activate corticospinal tract trans- and presynaptically. (Smith et al. 2011.) The I/O curve slope component is thought to describe the excitability occurrence in the cortex level (Siebner & Rothwell 2003). Changes in the curve over time indicate changes in the distribution of excitable elements in the cortical level or excitability in the corticospinal system. The slope of the I/O curve is highly dependable on all excitable elements under the stimulating coil. (Siebner & Rothwell 2003.)

2.5.2 Paired Pulse Stimulation

Inhibitory actions can be measured with paired-pulse TMS (Chen et al. 1998). The protocol owns a subthreshold conditioning stimulus and a suprathreshold test stimulus (Chen et al. 1998). These two stimuli make up a pair stimulation called paired-pulse. With this method interstimulus interval, ISI, is an important part to measure inhibition (Chen et al. 1998). Depending on the source, e.g. short 1-4 ms ISI has an inhibitory effect on neuronal circuits and longer ISI 8-15 ms creates a facilitatory effect. These paired-pulse stimulation variables are useful in studying the mechanisms of plasticity in cortical regions. (Chen et al. 1998.)

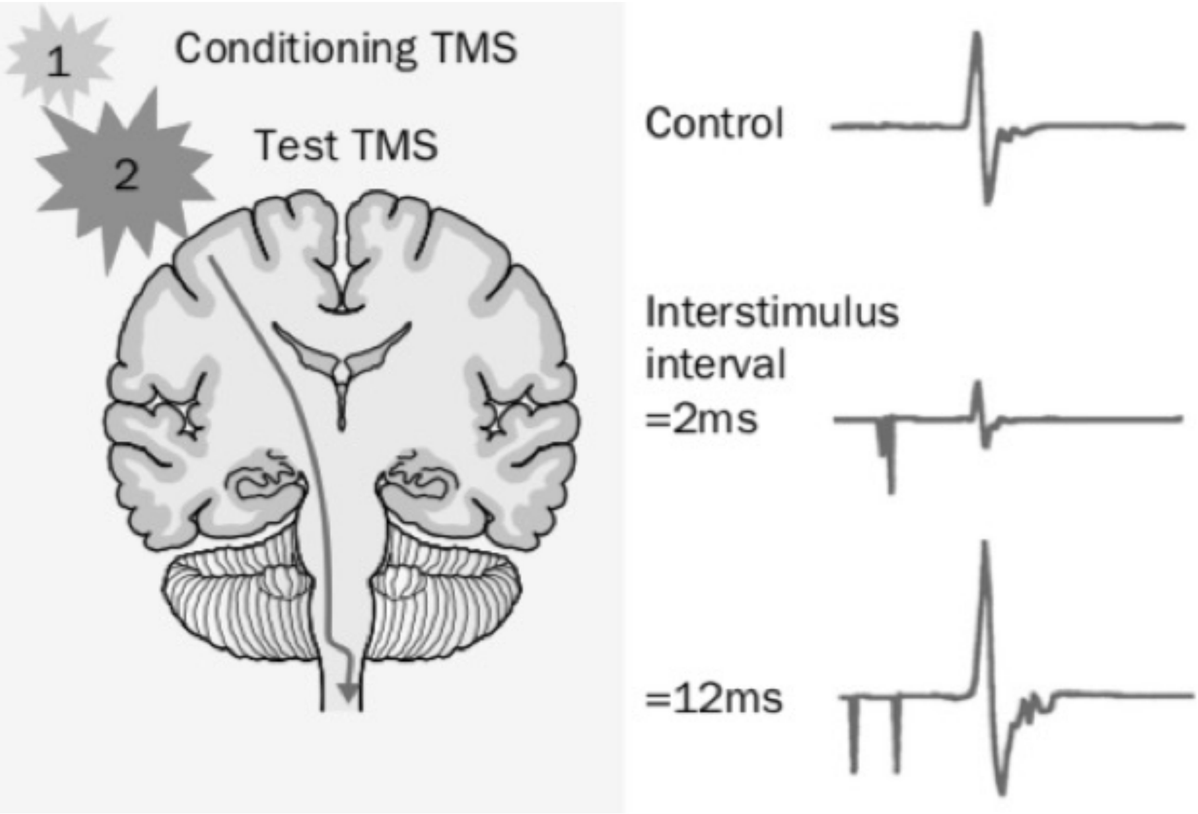

FIGURE 7. Paired pulse stimulation condition with two separate interstimulus interval affected MEPs (Kobayashi & Pascual-Leone 2003).

This paired-pulse stimulation can detect facilitatory and inhibitory interactions in the cortex (Kobayashi & Pascual-Leone 2003). Specific interstimulus interval is important to assess the wanted goals as seen in figure 7. Maximal inhibitory effects are able to be found with short interstimulus intervals. This interval is about 1-4 ms with a condition stimulus of 60-80 % rMT. When inhibitory levels reach their maximum level with the right intensity level, the MEP gets inhibited about 20-40 % rMT. (Kobayashi & Pascual-Leone 2003.) Chen et al. (1998) research found the most facilitatory effects in the interstimulus interval of 8-15 ms, Kobayashi & Pascual-Leone (2003) states the value bigger, 7-20 ms. The level of facilitation that can observed variates largely at interindividual level. Intracortical mechanisms under facilitation and inhibition are thought to be quite same between different motor representation areas. The effects seem to be created and found in the motor cortex level. (Kobayashi & Pascual-Leone 2003.)

Kujirai et al. (1993) article demonstrates inhibitory projections in motor cortex area including also both contralateral sensorimotor pathway and cerebellum. This specific conditioning test protocol gives evidence that inhibitory processes between areas are measurable. This inhibitory system is underlaid by the intracortical inhibitory system. (Kujirai et al. 1993.) When suprathreshold stimulus is applied with a specific time constant after subthreshold stimulus, the first stimulus suppresses the latter. The action that provides this effect is the first stimulus activating intracortical inhibitory neurons. (Ziemann et al. 1996.)

This inhibitory phenomenon in the motor cortex that can be measured with TMS and correct stimulus protocol is called short-interval intracortical inhibition (SICI) (Wagle-Shukla et al. 2009). The whole cortical summed output is formed from balanced inhibitory and facilitatory circuits. With proper stimulus parameters and components, TMS is a good technique to test these circuits. SICI protocol requires conditioning stimulus (CS) that is followed by this suprathreshold test stimulus (TS). There is also a specific interstimulus interval (ISI), which lies somewhere between 1 and 6 ms. There MEP gets inhibited. (Wagle-Shukla et al. 2009.) Facilitatory effect can be reached with ISI over 6 ms (Rothwell et al. 2009). The physiology underlying SICI includes ɣ-aminobutyric acid type A ($GABA_A$) receptors (Wagle-Shukla et al. 2009; Hallett 2000).

SICI is often used TMS method to study $GABA_A$ –ergic circuit excitability due to its easiness and familiarity (Rothwell et al. 2009). $GABA_A$ receptors are fast and ionotropic and they are mediated by SICI. It is thought, that SICI activates inhibitory systems low threshold sections, which then hyperpolarizes inhibitory postsynaptic potentials. This creates the inhibition of cortical output and measured TS. (Cash et al. 2017.)

Intracortical inhibition measured with paired-pulse stimulation reflects the cortex interneuronal activity (Fisher et al. 2002). Conditioning stimulus is so high that it activates neurons in the cortical region. Stimulus is still minor enough that is does not have detected descending influence in the spinal cord level. Conditioning stimulus is followed by a suprathreshold test stimulus. Conditioning stimulus affects the intracortical structures. The stimulus modulates the MEP amplitude induced by the test stimulus. (Hallett 2000.) Inhibition levels have been measured with different interstimulus intervals in figure 8 (Fisher et al. 2002). ISI of 1 ms with lower threshold does not cause the same level inhibition which ISI of 2.5 ms does. This ISI is thought to excite responses with two separate mechanisms. The first stimulus is thought to inhibit the second stimulus. (Fisher et al. 2002.) Maximum suppression happens when intensity of about 90% of the motor threshold (Rothwell et al. 2009).

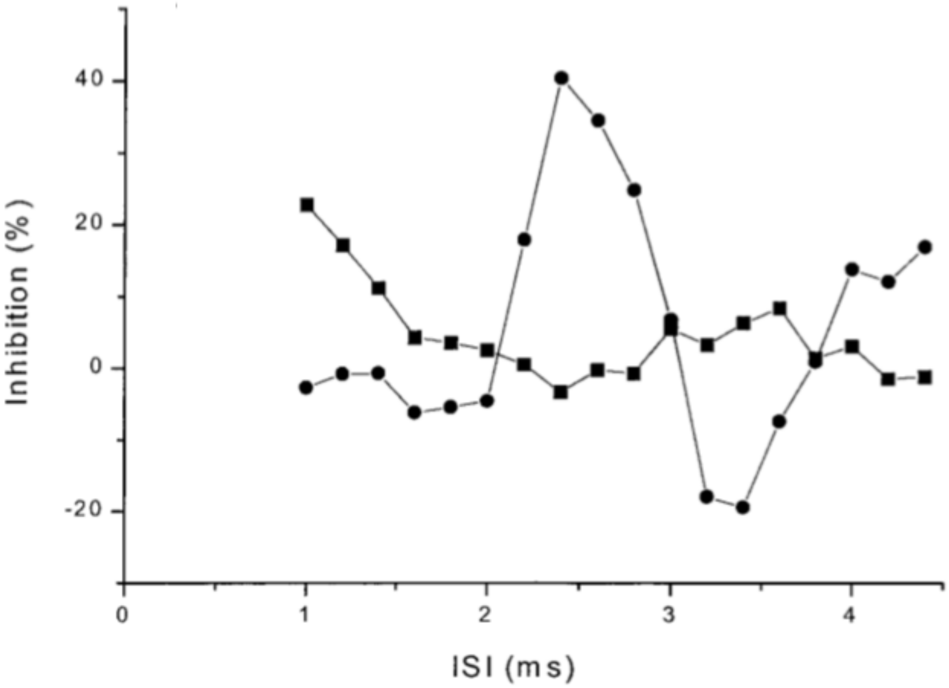

FIGURE 8. Inhibition levels expressed as dependent part of interstimulus interval (Fisher et al. 2002).

2.6 Peripheral Electrical Stimulation

In to the human nervous system applied peripheral nerve stimulation created depolarization reaches neuronal membranes and creates action potentials (Rossini et al. 2015). Central nervous system stimulation is thought to have similarities to the peripheral nervous system. Pulses that have amplitude of few milliamperes are driven into the nervous system. One of the most commonly tested variable is Hoffmann reflex, also known more as the H-reflex (Rossini et al. 2015). The H-reflex is an evoked reflex response measured with low-intensity electrical stimulation to a peripheral nerve (Niazi et al. 2015). The H-reflex is the most researched reflex in humans (Knikou 2008). Peripheral stimulation is often done at resting state. Latency and waveform do not change due to muscle activation and EMG gives unnecessary recording noises. (Rossini et al. 2015.)

The TA muscle can be stimulated from the common peroneal nerve (CPN) that runs near the head of fibula. A pulse width of 1 ms is recommended (Niazi et al. 2012). Electrically induced direct motor response is this context is shortened as M-wave and maximal peak-to-peak amplitude of this wave is maximal M-wave (Niazi et al. 2015). Niazi et al. (2012) found recognizable M-waves in TA muscle electromyography (EMG) trace with 5 mA increments delivered. Peripheral stimulation despite being a research method can lead to behavioural gains when it is combined with rehabilitative treatment. Specific type of repetitive proprioceptive feedback, which is self-generated, might be underlying skill acquisition. (Niazi et al. 2012.)

To the author’s best knowledge, H-reflex of TA has not been extensively studied. H-reflexes measured in TA muscle differ from SOL measured H-reflexes. One of the most noteworthy difference is the amplitude of TA H-reflex. This reflex amplitude is small compared to SOL reflex amplitude. (Brooke et al. 1997.) When the peripheral nervous system is investigated with TMS, H-reflex can offer valuable information about how the motor cortex and corticospinal tract influence motor control (Petersen et al. 2003).

3 AIMS AND HYPOTHESIS

Previous literature shows MEP alterations after 30-minutes of blindfolding compared to eyes open condition (Leon-Sarmiento et al. 2005). This visual deprivation also affected intracortical inhibition levels and corticospinal excitability levels (Leon-Sarmiento et al. 2005). Other research also indicates plasticity changes in reorganization of primary motor cortex level (Hirano et al. 2018). Hirano et al. (2018) had a visuomotor tracking test performed with ankle dorsiflexion and the results indicated reorganization in motor cortical level and skill learning. Perez et al. (2004) showed excitability changes in I/O curve and inhibition decrease after 32 minute motor skill training of ankle muscles. Improved performance was found in Floyer-Lea & Matthews (2004) study, where isometric contractions was performed with visuomotor tracking. They concluded that learning improved performance and automaticity through activity changes in cortical regions. They also concluded that a short-term motor skill training might be associated with cortical activity changes, somatosensory feedback processing and motor planning. (Floyer-Lea & Matthews 2004.) Khaslavskaia et al. (2002) refer that MEP increases indicates changes not only cortical motor areas but also subcortical neural structures and spinal level. Brodoehl et al. (2015) concluded that vision has a role in proprioception as eyes closure itself alters processing towards somatosensory perception.

The purpose of this present study was focused on how visual senses impact on motor skill learning and how it affects proprioception development. It is clear that visual sense possesses a great role in motor skill learning, so the present study aimed to focus on the acute effects of learning and the impact of vision. The transient visual deprivation protocol was added as eyes closed motor skill training. The study also aimed to assess the effect of just closing eyes, so an imaginary training condition was added as a constant training variable to eyes closed training. This was due to the fact that eyes closed training includes the learning effect without visual sense and mental imagery component. These effects were separated with the adding of imaginary training condition.

Therefore, separate transient visual deprivation protocols might induce different motor skill learning effects. These differences might occur in physiological and/or performance point of view. Although, visual deprivation is a relatively new aspect in motor skill learning research, it could be argued that visual deprivation protocols might improve technique and motor learning. This research used goal oriented complex motor skill training with different visual impacts.

Hypothesis: Transient visual deprivation in motor skill learning enhances the training development through different processing strategies and increases the corticospinal pathway excitability through increased proprioception feedback and decreased inhibition.

Earlier literature suggests that visual alterations affect proprioceptive feedback processing and motor skill learning. Vision alterations change the attention and sense of dominance through feedback processing emphasis. Imaginary training is able to alter motor skill training through altered awareness and sensorimotor integration. Without visual dominance in motor skill learning, corticospinal excitability increases, enhancing overall performance through proprioception and inhibition alterations.

4 METHODS

4.1 Subjects

Ten healthy and physically active students volunteered to participate in the study. There were three males and seven females, with mean age of 24 years (±2.2). Due to the methods used in this study, specific criteria had a to be met for subjects to be eligible. The contraindications included epilepsy, swoon or seizure-related activity, low blood pressure from approximately one hour still positioned sitting time, electric pacemakers or child expectancy. None of the subjects who participated in the study had any of the contraindications listed above. All subjects completed a document assessing the criteria, information from general health and significant data important to the study design.

Also, the subjects' current hobbies and activities from the hours prior to the measurements were recorded. All measurements were held in the morning or forenoon. This prevented the possibility of subjects being tired from physical activity. Because the study contained maximal efforts and joint movements, the subjects' physical activity level was assessed also as a precaution. Every subject was given the study structure plan, general information letter and subject recruitment letter by email. They were also given notice about privacy protections accepted by the ethical board of the University of Jyväskylä via email. A quick brief from all the above was given verbally in the first visit before measurements and written consent was signed by every subject. Subjects also gave written consent about privacy protections used in the study before filling the background information document.

4.2 Experimental Design

The complete experimental design of this study was created to consist of four visits (fig. 9). These four visits were thought to be the most acceptable for to subjects' participation. With this study design, one visit took approximately 120 minutes and the visits were divided into several weeks.

The first training session was solely a familiarization session with the study design. The second, third and, fourth visits were measurements days. Between these measurements days there were minimum of 17 days non-training period where subjects were instructed to live as normally as possible.

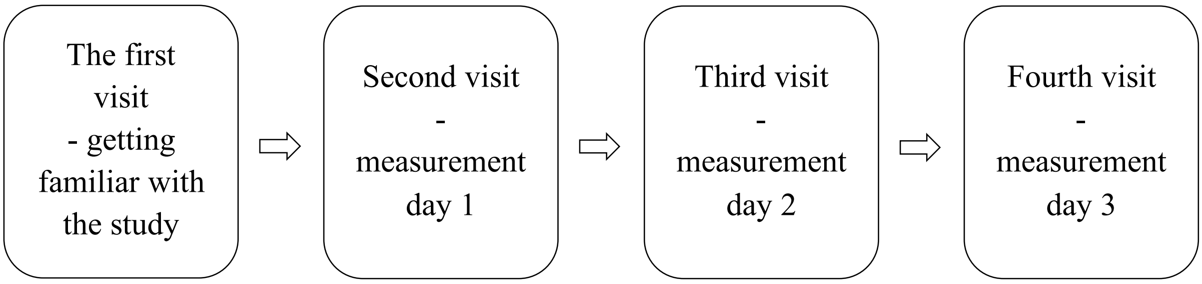

FIGURE 9. The study design with the first visit and the rest of the visits as measurement days.

4.2.1 Familiarization Session

The first visit contained three important aspects prior to participation in the actual study. First, the summary from the structure and experimental design of the study, subjects' rights, privacy protections and the ethical letter was provided and read. Secondly, the subjects' written consent form was signed (appendix 1), the background questionnaire completed (appendix 2), and the form regarding the information significant to the study was given. This consisted of brief instructions about the methods and equipment to be used in the study.

The third aspect of the first visit was the Movement Imaginary Questionnaire - 3 (MIQ-3). All subjects received the same instructions from the same researcher responsible for the questionnaire. First, the subject privately read the instructions of the questionnaire (appendix 3), which was translated into Finnish (appendix 4) from the original Hall & Pongrac (1983) version MIQ-3 by the researcher (Williams et al. 2012). After the subject had read the MIQ-3 information, the researcher held the questionnaire to the subject as informed in the questionnaire rules. This took approximately 20 minutes. After completing the MIQ-3, subjects were free to ask any questions about the study and its execution. The complete visit took less than an hour.

4.2.2 Measurement Sessions

All subsequent visits were considered measurements days and were identically structured. They lasted approximately 120 minutes and consisted of the same constant measurement protocol with only the skill training method changing between measurement days. At the beginning of the second visit (i.e., the first measurement day), the order of the skill training method was randomized. Randomization was done with an online generator that created equally-distributed randomized orders of training conditions (Randomization.com 2017).

As a result, four subjects started with the eyes open condition, three with the eyes closed condition, and three with the imaginary training condition. The same randomization order continued in the rest of the measurement days. The randomization was made for all the subjects at the same time to make sure each training condition had equal numbers from three to four subjects in every training condition in every visit.

4.3 Measurements

For each measurement, subjects were in a seated position as comfortable as possible in custom made dynamometer chair (Neuromuscular Research Centre, University of Jyväskylä, Jyväskylä, Finland). The chair was adjustable in the horizontal direction to the subjects' leg length. The backrest of the chair was not adaptable. The headrest was modifiable in the vertical direction. Subjects' arms were resting in their lap to match the most possible state of comfort. The chair adjustments were the same for the same subject during every measurement.

Muscle activity of TA was measured with self-adhesive surface electrodes (Blue Sensor N, Ag/AgCl, 0,28 cm, Ambu, Ballerup, Denmark). Before placing electrodes, the skin around the area of interest was shaved, abraded, and cleaned with alcohol to minimize possible resistance effects to a minimum. Electrode placement was done according to SENIAM (Surface Electromyography for Non-Invasive Assessment of Muscles, SENIAM) recommendations. Electrodes were placed over the TA muscle belly at 1/3 from the tip of fibula towards the medial malleolus line and with an interelectrode distance of 2 cm. The reference electrode was placed on the medial malleolus bony surface. For electrical stimulation, SENIAM recommendations were also used. The CPN was electrically stimulated from the lateral side of the proximal end of the fibula. A double electrode wire was used to deliver an electrical pulse. A single rectangular pulse was delivered with a duration of 1 ms (DS7AH, Digitimer Ltd., Hertfordshire, UK). A visual evaluation was made in determining the stimulation site that elicited a minimal response in SOL and a maximal amplitude response in TA.

Electrodes were placed while the subject was in a seated position with the knee resting in 90° of flexion and hanging downwards from the table. The most EMG signals were amplified (NL824, Digitimer Ltd., Hertfordshire, UK) at 1000 gain and max M-waves at 100 due to their peak-to-peak amplitude otherwise exceeding beyond the sampling window. An A/D converter (CED1401, Cambridge Electronics Design, Cambridge, UK) was used to sample and record the signals. Spike2 (version 6.17, Cambridge Electronics Design, Cambridge, UK) and Signal4.11 (Cambridge Electronics Design, Cambridge, UK) software was used in data collection. All measurements were encoded beforehand to ensure all data collection ran smoothly and identically for every subject. This was also beneficial due to the avoidance of major time-consuming typing mishaps. Every measurement was preceded with information for the subject for upcoming structures and timetables. Measurements started by pushing the start button of the software used and ended automatically when specific data collection were done.

TMS stimulation pulses were delivered with Magstim BiStim^2 (Magstim, Whitland, UK) with double-cone-coil held by the researcher. In every TMS measurements, there was attention task to count from 200 to 0 as in Kumpulainen et al. (2015). The TMS coil was held still by the researcher above the subjects' motor cortex during measurements. To maximize success, subjects were instructed to move as little as possible and to stay still. Between measurements, subjects were permitted to have a brief walk or standing period inside the room. This was due to avoid harmful complications to data due to prolonged time of sitting. Also, it was important for subjects to stay motivated and awake during measurements (Castro 2015).

The measurement protocol (table 1) consisted of eight to nine pre-measurements, motor skill training and six to seven post measurements. The measurement protocol (table 1) of the measurements was almost identical for all measurement days, except the imaginary training had an additional motor skill assessment. Each measurement day started with a briefing about that day's session. The measurement protocol in table 1 consists of abbreviations from the different measurements. All measurements are explained throughout the text.

TABLE 1. The measurement protocol of the study. There were three different training conditions, consisting of eyes open, eyes closed and imaginary training. The training order was randomized for every subject.

Eyes open training	**Eyes closed training**	**Imaginary training**
PRE measurements	**PRE measurements**	**PRE measurements**
MVC & RFD	MVC & RFD	MVC & RFD
Max H-reflex	Max H-reflex	Max H-reflex
Max M-wave	Max M-wave	Max M-wave
Hotspot	Hotspot	Hotspot
rMT	rMT	rMT
SICI	SICI	SICI
I/O curve	I/O curve	I/O curve
IJPR	IJPR	IJPR
		PRE Motor skill assessment
Skill training – eyes open	Skill training – eyes closed	Skill training – imaginary
POST measurements	**POST measurements**	**POST measurements**
IJPR	IJPR	IJPR
SICI	SICI	SICI
I/O curve	I/O curve	I/O curve
Max H-reflex	Max H-reflex	Max H-reflex
Max M-wave	Max M-wave	Max M-wave
MVC & RFD	MVC & RFD	MVC &RFD
		POST Motor skill assessment

MVC and RFD. Maximal voluntary contraction (MVC) was performed with ankle dorsiflexion movement. The measurement included two submaximal warm up contractions which was followed by three maximal voluntary contractions. For the three maximal contractions, identical instructions were given for all subjects. Instructions included contractions to be produced as fast and as forceful as possible. The period between contractions were timed according to the subjects own subjective feeling of readiness to perform the next MVC. When subjects felt ready, researcher started a 10 second time window in which the contraction were to be produced. Subjects were instructed to perform one MVC during this time window. From the three performed MVC repetitions, the repetition with the largest peak value was deemed as the subject's MVC. MVC measurement were identically performed pre and post motor training. The rate of force development (RFD) means actively producing great muscle strength in a short time window. In this study, RFD was calculated from the MVC force-time curve by marking the first force peak with cursor. Then RFD value came from dividing the MVC value with the time from the beginning of MVC EMG activity to the marked force peak. RFD quantifies neuromuscular systems adaptability to training (Gruber & Gollhofer 2004). With respect to skill training, RFD could be meaningful via force development improvements in the neural drive. This means that adaptations due to skill training could include adaptations to RFD. If skill training includes explosive type protocols then adaptations in RFD could be explained by adaptations in motor unit recruitment patterns. (Gruber & Gollhofer 2004.)

Electrical stimulation. Maximal H-reflex and maximal M-wave were measured with electrical stimulation created by 1 ms rectangular pulses to the CPN (Perez et al. 2004; Hirano et al. 2018). Both were measured with bipolar surface electrodes from TA muscle belly. An electric pulse was given to CPN from near the hollow of the lateral side of the knee. Max H-reflex and max M-wave peak-to-peak amplitudes were recorded. With max H-reflex, stimulation was started at low intensities (0.1 mA) and incremented with small steps (0.05-0.1 mA in relation to subjects previous results) to find the maximal H-reflex. The intensity continued to increase until H-reflex disappeared and max M-wave started to rise. Maximal H-reflex was documented from the largest amplitude, that usually was followed by the H-reflex disappearance when increasing the stimulus intensity. Maximal M-wave recording was performed with the same pattern of increasing intensities, but the starting intensity was near maximal H-reflex amplitude evoked intensity and increases were done usually in steps of 5 mA in relation to subject feeling and EMG response.

TMS. Single-pulse TMS stimulations were given to identify the correct hotspot, i.e. the optimal stimulation site for TA (Sivaramakrishnan et al. 2016). According to Sivaramakrishnan et al. (2016), the optimal hotspot for TA can be identified 1.60 cm lateral and 0.80 cm posterior from the vertex with healthy subjects. The complete leg area lies beneath the scalp surface in the depth of 3-4 cm embedded in the interhemispheric fissure. (Sivaramakrishnan et al. 2016.) The hotspot was found with estimated above resting motor threshold (rMT) stimulation intensity. Various sites were circled next to the presumed hotspot and MEP was elicited from contralateral to the stimulated hemisphere. (Rossini et al. 2015.) A double-cone-coil was used as leg areas are more easily targeted with this coil. Multiple studies with TA muscle or leg areas as target backs this up (Avela & Gruber 2011; Groppa et al. 2012; Beaulieu et al. 2014; Mrachacz-Kersting & Stevenson 2017; Hirano et al. 2018).

The motor threshold indicates the lowest possible intensity where magnetic stimulation can evoke a response (Perez et al. 2004). The rMT was measured with T.M.S. Motor threshold assessment tool (MTAT 2.0). This is based on adaptive parameter estimation by sequential testing (PEST) (Borckardt et al. 2006). This test provides the rMT estimation when accuracy is more evident than efficiency (Borckardt et al. 2006). This procedure uses the probability of the lowest stimulus intensity that creates a MEP with a 50 % or more chance presented by Jonker et al. (2019) in their study, which refers to Awiszus & Borckardt (n.d.) created software tool. This method provided rMT value with approximately 15 stimuli with a confidence interval.

Short-interval intracortical inhibition. Short-interval intracortical inhibition (SICI) was assessed mostly according to the Perez et al. (2004) study, where TA muscle was measured before and after 32-minute training. This study used skill, non-skill or passive training interventions. With TMS, a conditioning stimulus (CS) was given below rMT to inhibit subsequent suprathreshold test stimulus (TS). CS was 70 % rMT and TS 120 % rMT. (Perez et al. 2004.) The Perez et al. (2004) study used ISI according to Fisher et al. (2002), who considered ISI to be 2.5 ms due to the voluntary activity reduced inhibition effect with this ISI the most. After starting the measuring software, the measurement was automatically completed after the correct number of stimuli. 15 stimuli of 70 % rMT CS and 15 stimuli 70

% rMT CS followed by 120% rMT TS were given in randomized order. With four-second intervals in between, SICI measurement was two minutes long.

Input-output curve. The input-output curve (I/O curve) was measured before and after training. The measurement was encoded to happen independently after intensity set up and pressing the start button. I/O curve set up was modified from Castro (2015) thesis. Stimulation intensities were then assessed to be 90 %, 100 % (rMT), 105 %, 110 %, 120 %, 130 %, 140 % and 150 % of rMT. This makes a total of 8 intensity levels. Each level had ten stimuli applied to the motor cortex over the TA area. While the I/O curve was measured, all the intensities were obtained in a randomized order. These intensities give a general evaluation of EMG responses providing information about the corticospinal pathway excitability at a relaxed state (Carroll et al. 2001). According to Carroll et al (2001) the ISI should vary randomly. In this study, the randomization of ISI was assessed according to Castro (2015) thesis, where it was randomized to be between 7-10 seconds.

Proprioception assessment IJPR. Proprioception measurements were concluded according to Han et al. (2016) article. The most suitable method for this study given the available equipment was passively done ipsilateral joint position reproduction (IJPR) (Han et al. 2016). The complete test was done in the ankle dynamometer. The ankle was strapped and taped to the dynamometer pedal. The pedal movement pattern was encoded beforehand to automatically go through the test. The IJPR measures proprioception from the ipsilateral side (Han et al. 2016), which in this study was left lower limb and the TA. The target was set up as left ankle and the movement the IJPR test produced was dorsiflexion. In this movement, the TA is acting as an agonist. This predetermined target joint position was passively presented to the subject (Han et al. 2016).

After the target position was presented, the ankle was repositioned passively to the starting position. The starting position was held five seconds. After this the test was set up to go passively with the same angular velocity ten times further. The subject needed to push a custom-made button (Neuromuscular Research Centre, University of Jyväskylä, Jyväskylä, Finland) to create a mark to the pedal angle they thought was the target angle presented earlier. After the pedal moved ten times above the target angle and subjects had pushed the marking button in every trial, the test ended automatically by stopping the pedal. The total test took time four minutes. The IJPR test phases are presented in figure 10.

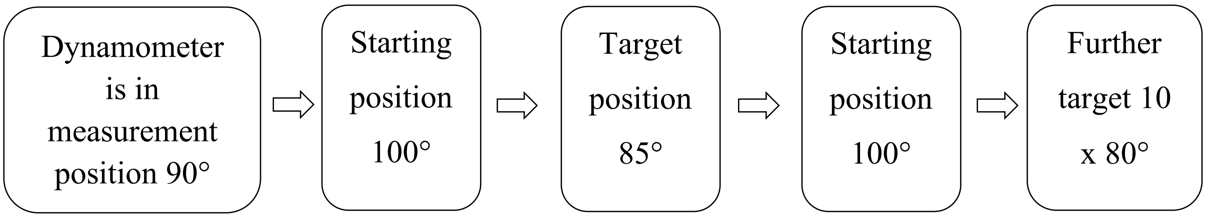

FIGURE 10. IJPR test structure. Dynamometer pedal moved from measurement position to IJPR test starting angle (5 s), then to target position (2 s), back to starting position (5 s) and ten times further than target position (2 s). (Modified from Han et al. 2016.)

4.4 Motor Skill Training

This study used a motor skill training protocol based on force-time curves as a training method. This consisted of target and training waves. An initial force-time curve was named as the target wave. Then, the subject needed to produce a force-time curve as similar as possible to the target wave. This was considered the training wave. The principle of this training was that the subject created multiple force-time curves as training waves to produce identical curves like the target wave. This lasted for 20 minutes and the training was done with ankle dorsiflexion movement in the ankle dynamometer.

Both waves were on their channels in Spike2 (version 6.17, Cambridge Electronics Design, Cambridge, UK) connected with the ankle dynamometer. Subjects were instructed to pay close attention to temporal features, wave amplitudes as force indicators, specific waveforms and starting and ending phases. Motor training was done in custom-made (Neuromuscular Research Centre, University of Jyväskylä, Jyväskylä, Finland) dynamometer chair in the same individualized position that all measurements was done in. For motor training, subjects were in a seated position with their knee in a resting position close to full extension and their shoeless ankle strapped in 90° dorsiflexion. The subject had a TV screen, situated approximately in one-meter distance in front of the dynamometer chair, that constantly displayed the target wave and online performance of the training wave. One trial took a total of ten seconds and the target wave was eight seconds long.

The motor skill training was created from generic sinusoidal temporal signal segments with Spike2 (version 6.17) programming language. Timing of the start, duration, amplitude, quantity of the cycles, transition in time, location in relation to zero level and sampling frequency were all incorporated. In the final signal the segments were connected in succession and the complete signal was timed to have a duration of exactly 10 seconds. Signal included 10k samples.

For data collection, an automatic data window was created with adding channels and replication signals. Both channels' limits were assessed to match subject related reference force level with a minimum of 5 Nm and a maximum of 110% MVC. The signal was added to the Spike2 on-line waveform playlist and was assigned with a waveform key. When the key was pressed, the environment for the data collection set and started the motor training waveform signal. There was a specific looping function under controlling the timing of separate data collection phases. Signal was repeated once and the collection was discontinued automatically. After this the software created a new data window for sequential data collection. The new collection was activated to show visible in the temporal phase of 27 seconds from the preceding collection beginning and started in the phase of 30 seconds.

The training was modified from Castro (2015). One motor skill training trial took exactly 10 seconds, and the feedback time was 20 seconds. From the feedback phase, three seconds were reserved as a preparing phase. This means that one training interval took exactly 30 seconds. The training session consisted of 40 trials, resulting in training time of 20 minutes. For all the subjects, training instructions were given similarly with identical goals to pursue. In the feedback phase, subjects always had a chance for visual feedback from the TV screen, which showed the latest training trial and target wave. This interval structure is seen in figure 11. The way visual feedback was given is presented in figure 12. The target wave was presented and instructions were given just before motor skill training. Instructions included the specification of timings and forces of the sections of the target wave.

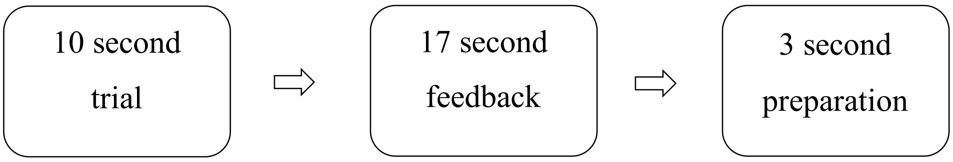

FIGURE 11. The structure of one motor skill training interval. The first 10 second trial was motor performance, which was followed by 20 second feedback. During the feedback phase, subjects had visual feedback from their latest trial and the target wave as force-time –curves provided for 17 seconds. After this, 3 seconds were reserved as preparation time for the next trial. This interval structure was performed 40 times.

The target wave was encoded mathematically to match the subjects' own MVC value. Then, for every subject MVC was measured and the maximal value was fed into Spike2 (version 6.17, Cambridge Electronics Design, Cambridge, UK) motor training configuration. This way every subject had the motor training matched to their MVC level.

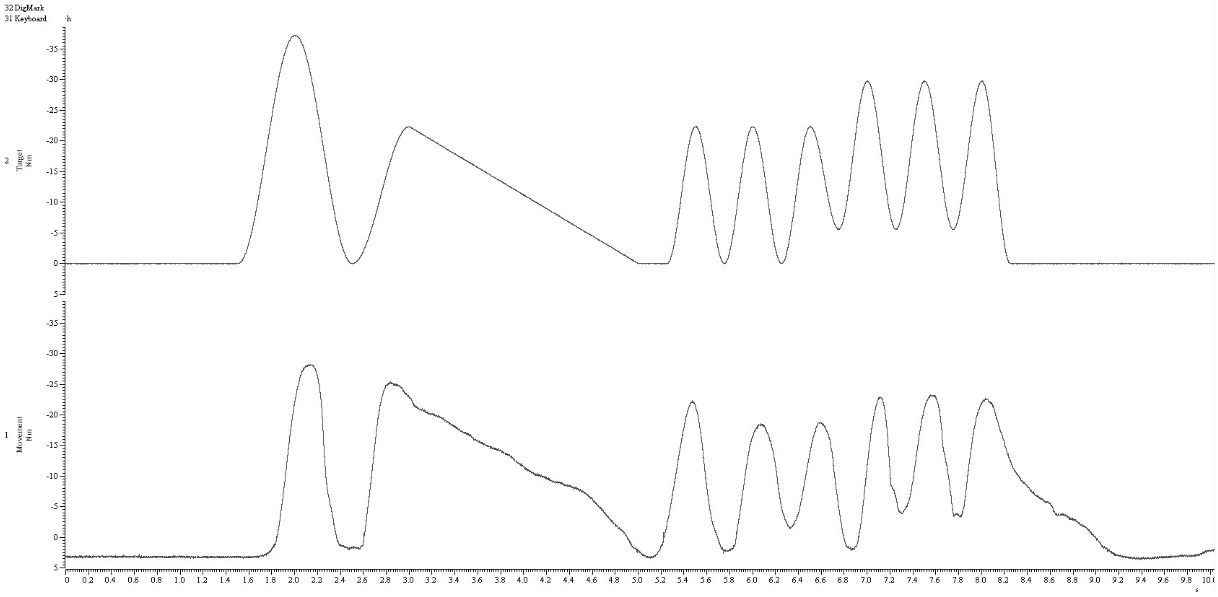

FIGURE 12. Example force-time –curves of the target wave (upper) and movement (lower) made by one subject trying to match the target and the way the feedback phase was presented during motor skill training. This target wave was used in all training conditions.

Figure 12 shows the target wave, which was matched to every subjects MVC value. The first wave is the MVC and its duration is one second rising in exactly 1.5 s after the training begins. The first wave was created to test subjects MVC at a specific time. The second wave was aimed to test a slow liberation of the force created to 50 % of MVC. This wave was from 2.5 s to 5.0 s and the rise of the wave being exactly 0.5 s and slope being 2.0 s. These two waves created ‘’the force’’ part of the training and six last waves created ‘’the rhythm’’ part. This rhythm part consisted of six waves and all of them taking exactly 0.5 s per wave. The first three waves from the rhythm part were set to the force level of 50 % MVC and the last three waves to the level of 75 % MVC. The third wave did not reach the zero-force level and relaxation. This second part aimed to test subjects’ skill acquisition with rhythms and quickness.

The actual motor performance of the ankle was identical in eyes open and eyes closed conditions and in imaginary training condition, the physical motor activity was replaced with imaginary training. The 17 second feedback phase was identical in all training conditions. When the feedback phase started, a command ‘’feedback’’ was given by the researcher, and subjects were free to look at the screen. In the preparation phase, the researcher counted down aloud the three seconds as ‘’three, two, one’’ and the following trial started. The researcher always kept the subject aware of preparation time, trial ending, and feedback time.

During the training trials of eyes open condition, the subjects focused their vision towards the marked spot. This spot was a big letter X taped on the wall left to the TV screen. During the preparation phase, subjects were instructed to change their gaze towards the spot away from the feedback screen. In the eyes closed and imaginary training conditions, the training was done with visual deprivation protocol. This concludes that none of the training conditions had online visual processing of the ongoing force-time –curve during the trial.

The imaginary training condition consisted of training done without any physical movement. The EMG data were scouted online to have zero levels of muscle activity. Minimal instruction was provided for the Imaginary training method so that the subjects would use the protocols they are comfortable with. In every condition, the distinct parts to pay attention to were instructed similarly. To sum up, imaginary training was done imaginarily without movements.

In the imaginary training condition, there was a specific motor skill assessment. Imaginary training gives results from the subjects' subjective point of view. The motor skill assessment was added to also obtain objective results. The subjects were instructed to report if they succeeded in the latest trial. This subjects' subjective success rate was marked down and repeated after every imaginary training trial. Before and after measured motor skill assessment consisted of three eyes closed training trials. These trials were at the beginning of imaginary training and after every measurement conducted that day. Therefore, imaginary training consisted of a total number of six eyes closed condition training trials, three pre and three post trials, and 40 trials of imaginary training. Motor skill assessment was added due to the possibility of this mode of training affecting adapting motor skills. All post measurements were done immediately after motor training and in the order given in table 1.

4.5 Visual Deprivation Protocols

The visual deprivation protocol was used in eyes closed and imaginary training conditions. The protocol included a ski mask, which was completely blackened to made eyesight impossible. The mask was put on during in the preparation phase at the latest so that the trial started with the mask already on. When the feedback phase started, subjects had permission to take off the mask and see the visual feedback.

The subjects were also informed to keep eyes closed behind the mask in these two conditions. In eyes closed, the training was done similarly to eyes open, except head position did not matter due to the mask. To keep conditions as similar as possible, the visual deprivation protocol was used similarly in imaginary training condition. This was due to the imaginary training being set up as a reference for eyes closed training condition.

4.6 Analysis

All data analysis was done in Signal4.11 (Cambridge Electronics Design, Cambridge, UK) except the motor training data was measured and analysed in Spike2.0 (version 6.17, Cambridge Electronics Design, Cambridge, UK) with a sampling rate of 1000 Hz. All data analysis was performed offline.

Pre and post values in MVC and RFD were calculated by averaging all subjects' measurement specific values. Pre to post changes were calculated by subtracting pre values from post values. The negative change in MVC means smaller peak forces in maximal contraction post values compared to pre values. The negative change in time to MVC peak force indicates faster time to reach maximal peak force in post measurements. Positive change is a result of slower contraction time in post measurements. In RFD, MVC was divided with time required to reach MVC peak force. Greater result or in other words, positive change, in RFD means either forceful contraction and/or faster contraction time.

Maximal H-reflex was measured as many times with increasing intensity until the amplitude of the reflex disappeared. Then the H-reflex with the largest peak-to-peak amplitude was recorded to represent spinal excitability. The maximal M-wave was measured with a large scale of intensities to find the maximal peak-to-peak amplitude of the M-wave. Multiple stimulations were done to find the maximal motor response. After increasing from small to larger intensities until the amplitude of M-wave no longer increased, the maximal peak-to-peak amplitude was documented. The analyses were done off-line in Signal4.11 (Cambridge Electronics Design, Cambridge, UK). The relation of max H-reflex and max M-wave is presented by dividing the absolute max H-reflex value with the same measurement session-specific max M-wave creating a H/M relation variable. This relation is comparable to the evaluation between sessions. Pre max H-reflex was scaled to pre max M-wave and alike in post values.

The TMS variables included hotspot, rMT, SICI, and I/O curve. These variables were analysed offline with peak-to-peak amplitudes in Signal4.11 (Cambridge Electronics Design, Cambridge, UK). The correct hotspot was searched from the supposed TA motor cortex area. The TA muscle area was circled with larger intensity to see which specific area evoked the clearest MEP. The rMT was measured and analysed with T.M.S. Motor threshold assessment tool (MTAT 2.0), as mentioned earlier. SICI was analysed with peak-to-peak amplitude separately from each trial by placing the amplitude of interest between two cursors. This analysis was done manually by the researcher. The complete I/O curve analysis was done with a script. The script file was laid over the result file of one I/O curve measurement and it automatically picked up the peak-to-peak amplitudes of every trial separately from the total amount of 80 trials.

The TMS variable I/O curve was also analysed as an area under the curve. The area under the curve was calculated from I/O curves at eight intensity levels (x-axis) and their averaged MEP/M values (y-axis) formed seven parallelograms between intensity levels. As a result, each I/O curve had one value reflecting the level of excitability in every pre and post conditions and also the change between them. All TMS data was visually evaluated to prevent picking up data with preceding muscular activity. Even if the slightest activity was observed from the EMG data of any measurement, the data were excluded.

4.6.1 Analysis of the Motor Skill Training

The motor training was collected and analysed manually in Spike2 (version 6.17, Cambridge Electronics Design, Cambridge, UK) software. Motor training trials were saved in separate files, which were then analysed offline. The training wave was matched to the target wave by creating a virtual channel. In this channel, the training wave was reduced from the target wave. This new channel provided the difference between the target and training waves. This difference was then exported to a Microsoft Excel file. This was done for all training data.

This difference between target and training waves was then divided into two significantly separate phases due to shape and rhythmic parts of the force-time curve. The first ''force'' part was 0.0-5.0 seconds and the second ''rhythm'' part was 5.1-10.0 seconds from the total trial. While subjects had 40 trials from every motor training condition, results were averaged as one total value from every trial, force phase and rhythm phase. The motor training was also divided into four parts of training trials. The first part was trials 1-10, second 11-20, third 21-30 and fourth 31-40. This way the motor training could be analysed qualitatively between the start and end of the training.

Motor skill training results were collected as numerical difference named error points between the training wave and the target wave. The results were analysed in earlier mentioned parts named total, FP and RP due to the themes of training trials. The complete motor skill training task included 40 trials and the distribution of trials was four times ten trials in numerical order. The less error points the performance produced the more accurate it was.

During the imaginary training condition, each subject also had their subjective rate of success counted. After every trial, subjects answered a question of ‘’did you succeed?’’ in that specific trial. The subjective rate of success was counted as percentual success from the total number of imaginary training trials. In imaginary training condition, motor skill assessment was added to quantify the degree of possible development achieved with imaginary training. This was concluded as three eyes closed trials done just before imaginary training and as the latest of all measurements. These three pre and post motor skill assessment trials were identically performed with eyes closed training.

4.6.2 Analysis of the Proprioception Test

The proprioception test data was collected and analysed in Signal4.11 software (Cambridge Electronics Design, Cambridge, UK). The analysis was made manually by the same researcher (fig. 13). The test included ten trials, all saved in the same file as separate frames. Proprioception test provided data as an angular difference. Into the data, the subjects marked thought-to-be target positions during the measurement. The target position was marked to happen at the same time, so it was able to be tracked from the data. The pedal movement was tracked with angular change.

The temporal and angular averaged differences were calculated between the subject marked target angle and the target angle. Angular error was calculated as a difference from the target angle per subject and then the angular error was averaged between subjects. Smaller error indicates better test performance. Absolute change was calculated by subtracting post error from pre error.

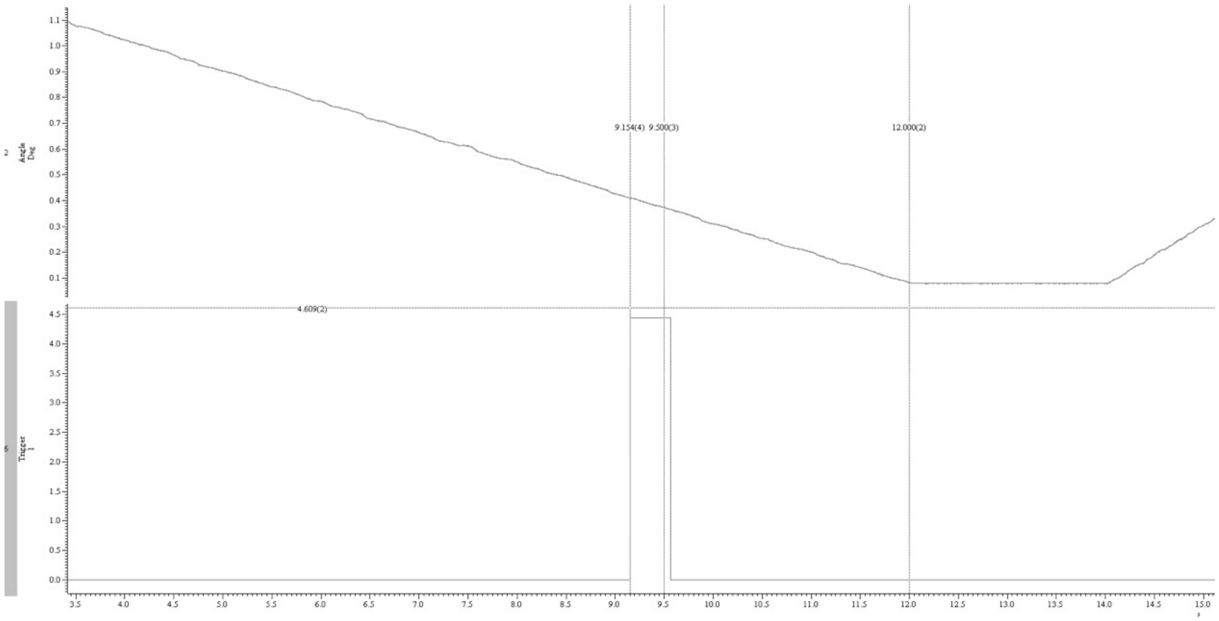

FIGURE 13. An example of proprioception test trial analysis presented as the angular movement of dynamometer pedal (channel 2 above) and subject marked trigger (channel 1 below) to the estimated target position. The cursors represent the subjects estimated ankle target position (cursor 4), the real calculated target position (cursor 3), and the pedal movement ending (cursor 2). Subjects angular error in this trial is the difference between cursors 3 and 4.

4.6.3 Statistical Analysis

Statistical data-analyses were done in SPSS2.0 (version 24, IBM SPSS Statistics Data Editor). In statistical correlations, non-parametric Spearman's rho was used with a significance level of 0.050. Due to a small sample size (n=10), statistical analysis of significance was assessed with a nonparametric test of Wilcoxon's signed-rank test with a significance level of 0.050 and confidence intervals of 95%. Three or more values' significance was measured with Related-Samples Friedman's Two-Way Analysis of Variance by Ranks with a significance level of 0.05. Level 0.05 significance is marked with a star (*), 0.01 level with two (**), and 0.001 level with three (***). The standard deviations were calculated with Microsoft Excel function for sample set of data. Standard deviations were also verified with SPSS2.0 (version 24, IBM SPSS Statistics Data Editor).

5 RESULTS

5.1 Motor Skill Training Development

Motor skill training results are presented in table 2. The table total error points show that eyes open training trials 31-40 had significantly better performance when comparing to all total error points ($p<0.05$), except eyes closed total trials 31-40. Also in FP, eyes open trials 31-40 had significantly better performance when comparing error points to other FP trials ($p<0.05$), excluding eyes closed trials 31-40. Even though there are indications that eyes open trials 31-40 had the best performance in RP, the performance was not statistically different compared to other RP trials.

TABLE 2. Motor skill training error points per trial force part (FP) and rhythm part (RP) and trial sequences.

	Trials 1-10	**Trials 11-20**	**Trials 21-30**	**Trials 31-40**
		Eyes open training		
Total	11.034 (±2.873)	10.026 (±2.524)	10.145 (±2.488)	9.223 (±1.935)
0.0-5.0 s FP	5.515 (±1.655)	5.049 (±1.369)	5.100 (±1.271)	4.279 (±1.017)
5.1-10.0 s RP	5.516 (±1.684)	4.975 (±1.326)	5.044 (±1.302)	4.952 (±1.035)
		Eyes closed training		
Total	11.034 (±1.949)	10.727 (±2.212)	10.242 (±2.012)	10.136 (±2.082)
0.0-5.0 s FP	5.552 (±1.232)	5.230 (±1.267)	4.880 (±1.223)	4.965 (±1.442)
5.1-10.0 s RP	5.481 (±1.065)	5.495 (±1.118)	5.360 (±0.923)	5.169 (±0.748)
		Imaginary training		
	Pre motor skill assessment		Post motor skill assessment	
Total	10.996 (±2.919)		10.637 (±2.125)	
0.0-5.0 s FP	5.342 (±1.138)		5.585 (±1.256)	
5.1-10.0 s RP	5.653 (±2.148)		5.051 (±1.114)	

Inside eyes open condition, significances were found between total error points of trials 1-10 and 11-20 ($p<0.05$), 1-10 and 21-30 ($p<0.05$), 1-10 and 31-40 ($p<0.01$), 11-20 and 31-40 ($p<0.05$) and between trial sequences 21-30 and 31-40 ($p<0.05$). When significance was assessed from FP of eyes open training condition, three significant differences were found between trial sequences of 1-10 and 31-40 ($p<0.01$), 11-20 and 31-40 ($p<0.01$), and between 21-30 and 31-40 ($p<0.05$). From RP, a significant difference was between trials 1-10 and 11-20 ($p<0.05$) and between trials 1-10 and 21-30 ($p<0.05$).

From eyes closed training condition, one significant difference was found between trial sequences 1-10 and 31-40 ($p<0.05$). In FP, a statistically significant difference was found between trial sequences 1-10 and 21-30 ($p<0.01$) and between trials 1-10 and 31-40 ($p<0.05$). No significant differences were found between pre and post imaginary training error points.

No significant differences were found across training conditions from total error points in trials 1-10 or pre trials. However, imaginary training post trials and eyes open trials 31-40 had a significant difference ($p<0.05$) in total error points. In FP, eyes open trials 31-40 and imaginary training post trials had also a significant difference ($p<0.01$). No significant differences were found between training conditions in RP from first trials/pre and last trials/post. When significance was assessed in developments across training conditions, eyes open development had a significant difference with imaginary training development in total ($p<0.05$) and FP ($p<0.05$).

Motor skill training task results are also presented in figure 14, where combined error points in total, FP, and RP sections are divided by training conditions. Figure 14 shows indications of the best performance in total happening in the eyes open condition in every section, but the differences in performance success expressed as combined error points from all trials were not statistically significant. To clarify the results better, development in error points in every training between eyes open and closed trials 1-10 and 31-40 and imaginary training pre and post trials are presented in figure 15 below.

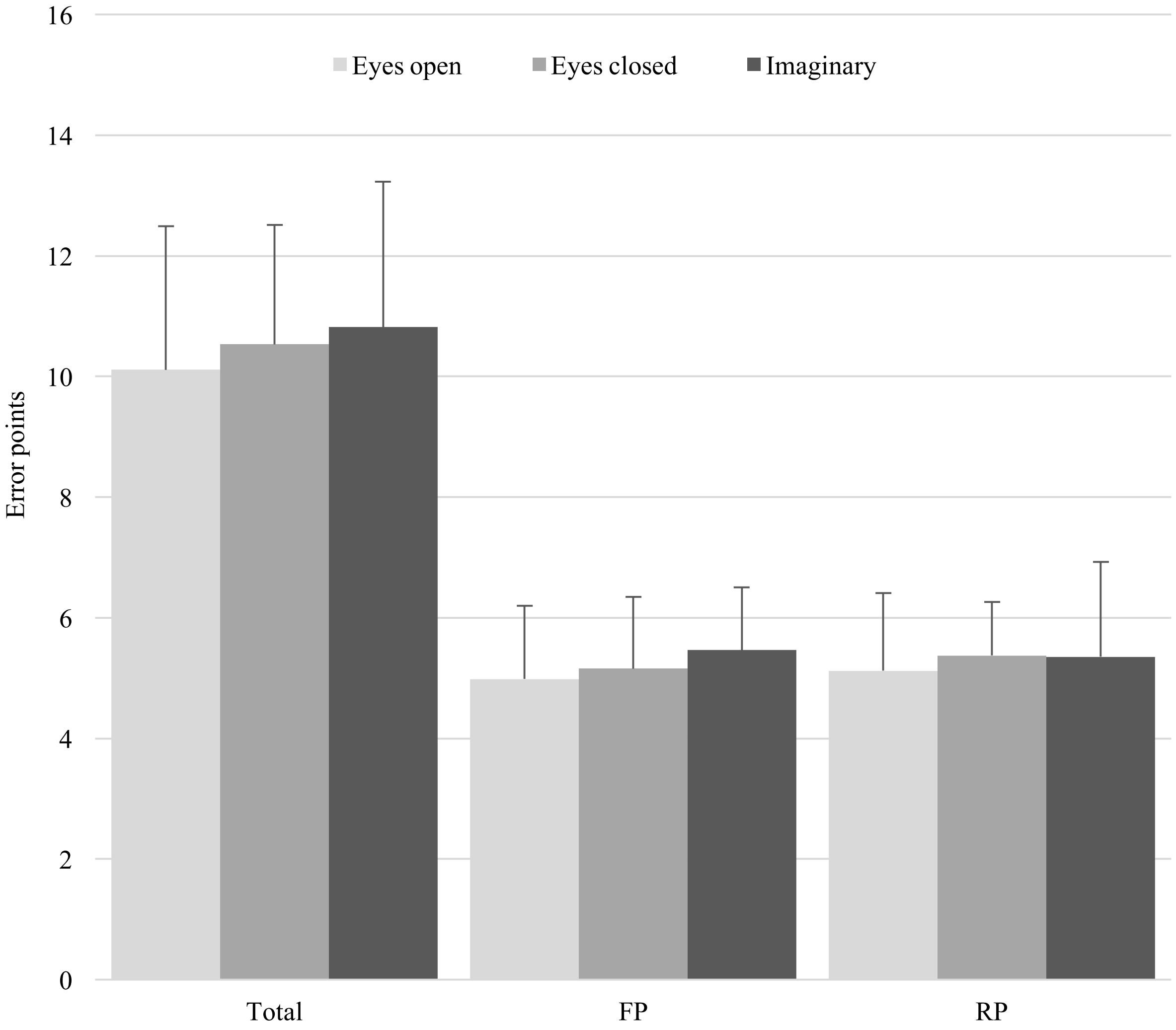

FIGURE 14. Total, force part (FP) and rhythm part (RP) error points and standard deviations in eyes open, eyes closed and imaginary training conditions from the whole motor skill training period (trials 1-40).

According to figure 15 presented error points, there was significant development in total and FP error points in eyes open and eyes closed training conditions. Imaginary training showed indications about the largest change in RP, but the change was not significant. Also, imaginary training showed a non-significant indication of a negative change in FP. There was a large variation between the subjects, which can be seen in standard deviations.

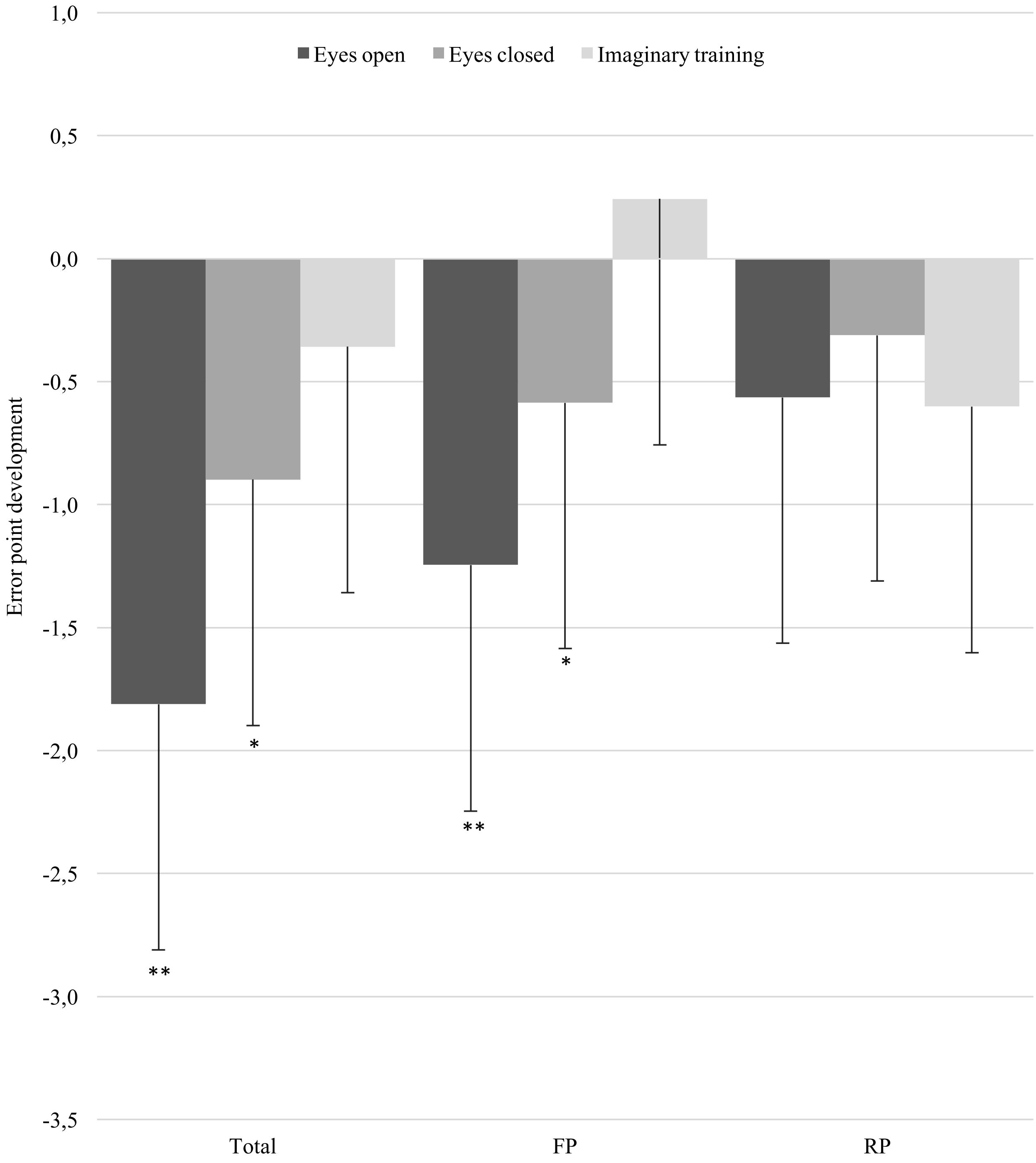

FIGURE 15. Motor training development in error points and standard deviations between eyes open and eyes closed conditions trials 1-10 to 31-40 and imaginary training pre to post trials in total, force part (FP) and rhythm part (RP) error point values.
* $p < 0.05$; ** $p < 0.01$

5.2 TMS Variables

MEP values in figure 16 are presented as averaged and separated pre and post MEPs of every I/O curve measurement condition. There are indications of growth from the small intensities towards the larger intensities. Statistical significances were found between small 90-105 % intensities and larger 130-150 % intensities in eyes open pre ($p<0.01$) and eyes open post ($p<0.05$), eyes closed pre ($p<0.05$) and, eyes closed post ($p<0.01$), imaginary training pre ($p<0.05$) and post ($p<0.05$). The imaginary training averaged MEP values showed indications of a positive excitability change in every intensity, and additionally the positive change in 120 % was statistically significant ($p<0.05$) (fig. 16). Eyes open training MEPs from pre to post showed indications of positive changes until 120 % and eyes closed training until 140 %. However, these changes were not significant.

There were indications of an imaginary training post having the largest averaged MEP values in six out of eight I/O curve intensities. These intensities were 90, 100, 110, 130, 140, and 150 %. Also, eyes closed post averaged MEP values indicated to be the largest in intensities 105 and 120 %. However, the averaged MEP values were not significant when compared to other training conditions or pre values.

Multiple correlations were found between I/O curve variables and motor skill training variables in each training condition. The most important correlations were in I/O curve intensity changes from pre to post and motor skill training developments. Eyes open correlations were between training development in FP and I/O curve intensities 90 % ($r=-0.842, p<0.01, n=10$) and 120 % ($r=-0.648, p<0.05, n=10$). Eyes closed condition had a correlation between training development in FP and I/O curve 100 % ($r=0.636, p<0.05, n=10$). Imaginary training had seven correlation between training development in I/O curve intensities. Development in FP correlated with I/O curve intensities 100 % ($r=0.842, p<0.01, n=10$), 110 % ($r=0.794, p<0.01, n=10$), 120 % ($r=0.721, p<0.05, n=10$), 130 % ($r=0.842, p<0.01, n=10$), 140 % ($r=0.794, p<0.01, n=10$), and 150 % ($r=0.879, p<0.001, n=10$) and development in RP with intensity 130 % ($r=-0.648, p<0.05, n=10$).

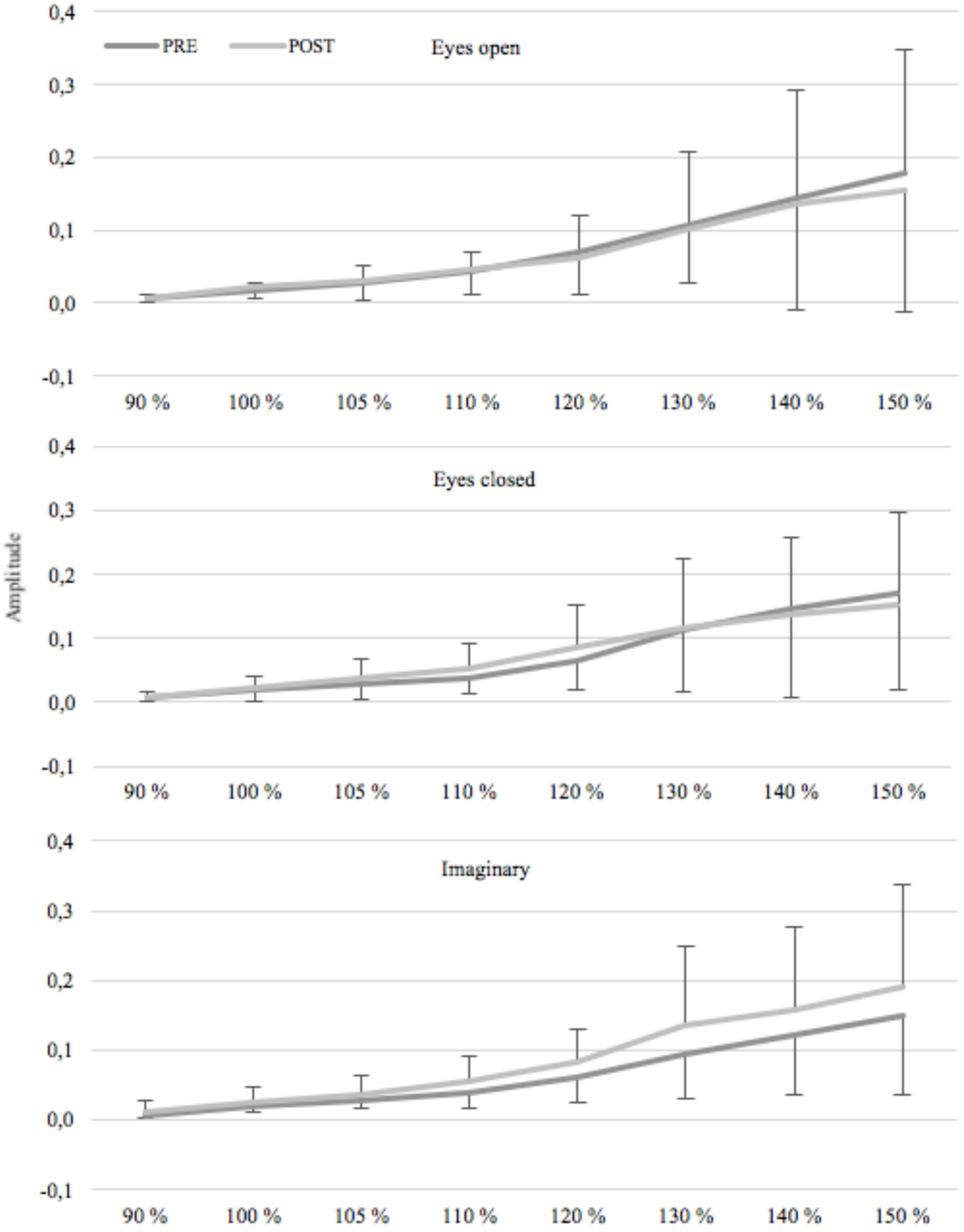

FIGURE 16. I/O curves MEP scaled to max M-wave pre and post absolute values and standard deviations in eyes open, eyes closed and imaginary condition.

Figure 17 shows the I/O curve absolute changes from pre to post measurements. The figure presents every training condition I/O MEP change per intensity level. Compared to other training conditions, there were indications of imaginary training having the largest changes in every intensity, except 105 % indicated the largest change in eyes closed condition. However, statistically significant difference changes between conditions were only found from imaginary training 120 % and eyes open 120 % (*p<0.05*), and imaginary training 150 % and eyes closed 150 % (*p<0.05*). Other changes were not significant between different training conditions. A significant development was found in imaginary training 120 % (*p<0.05*) (fig. 17).

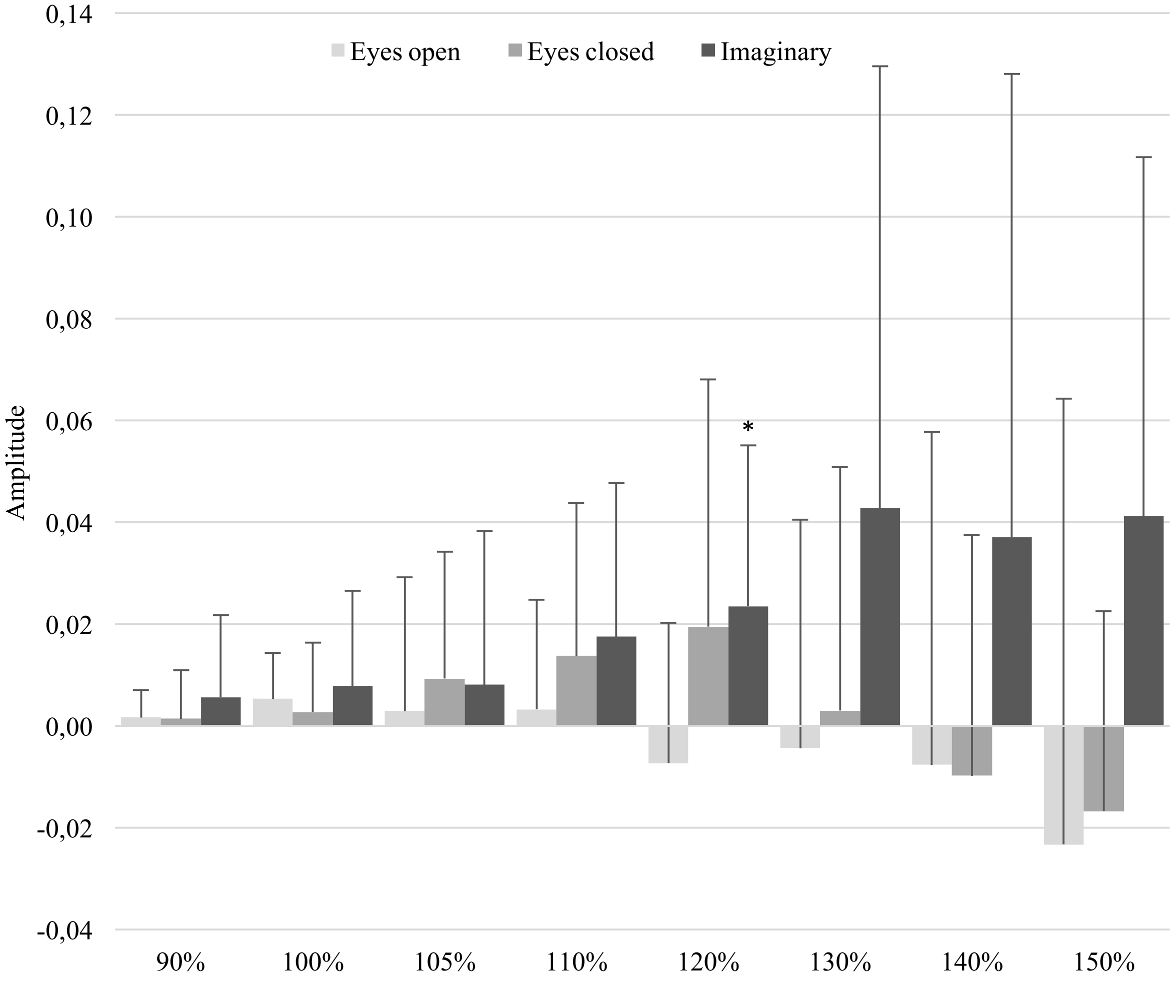

FIGURE 17. I/O curves MEP scaled to max M-wave absolute changes and standard errors from pre to post in eyes open, eyes closed and imaginary training conditions.

* p < 0.05

The last I/O curve is also presented as the MEP area under the curve (AUC) (fig. 18). In the imaginary training condition, there was an indication of the most positive change between pre and post when compared to other training condition changes. Figure 18 refers also imaginary post having the greatest value, but these across conditions compared changes and values were not significant. The results indicate that change in imaginary training was over 36.0 %, while eyes open change decreased 4.7 %, and eyes closed increased by 4.7 %. From these changes, one statistically significant difference was found and it was between pre and post AUC (*p<0.05*) in the imaginary training condition (fig. 18). AUC had also a correlation with motor skill training in imaginary training condition. AUC post values correlated with FP development from trials 1-10 to 31-40 in imaginary training condition (*r=0.648, p<0.05, n=10*).

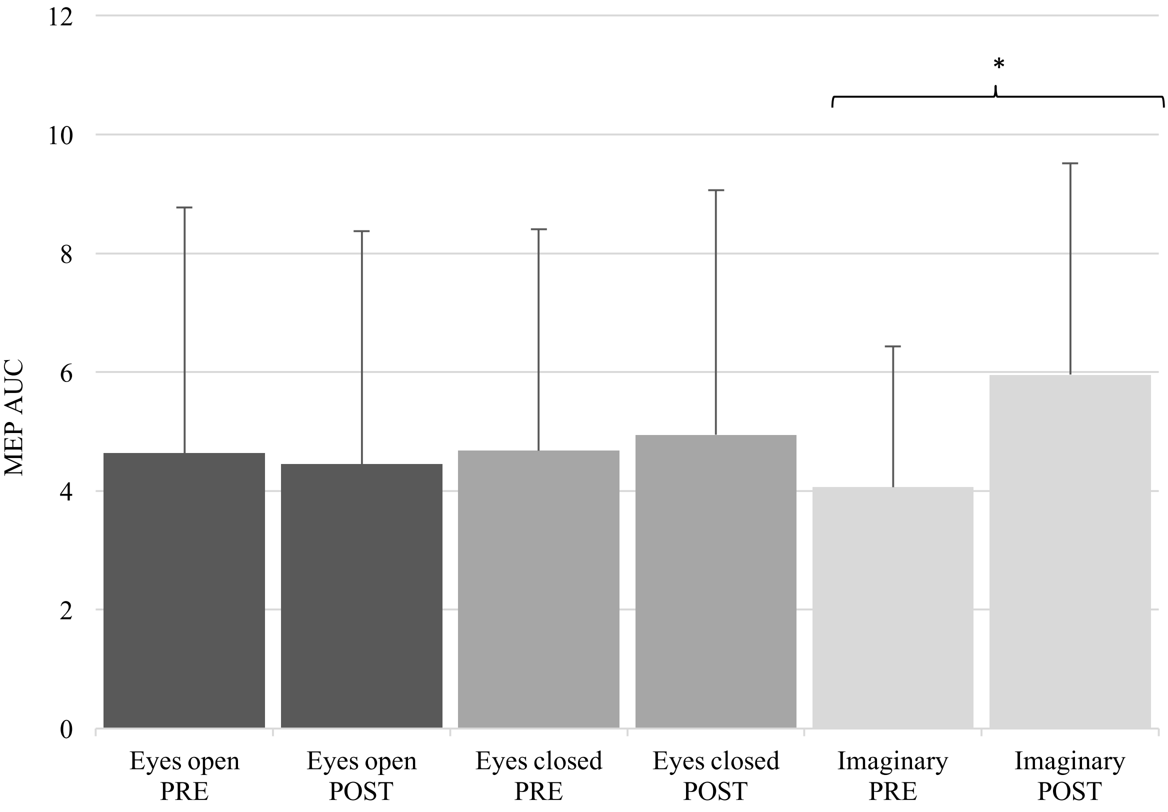

FIGURE 18. MEP scaled to max M-wave as area under the curve (AUC) calculated values and standard deviations from I/O curve pre and post measurements in every training condition.

* $p < 0.05$

Short interval intracortical inhibition (SICI) is presented in figure 19 with absolute pre and post values and their absolute changes. The figure shows indications that the largest inhibition decrease happened in eyes closed condition and a lesser decrease happened also in imaginary training. However, these decreases were not statistically significant. Eyes open condition seemed to increase intracortical inhibition, but not statistically. No significant differences were found from SICI between pre and post values of specific training condition. Additionally, a significant difference was found between SICI eyes open and eyes closed pre values (*$p<0.05$*) (fig. 19).

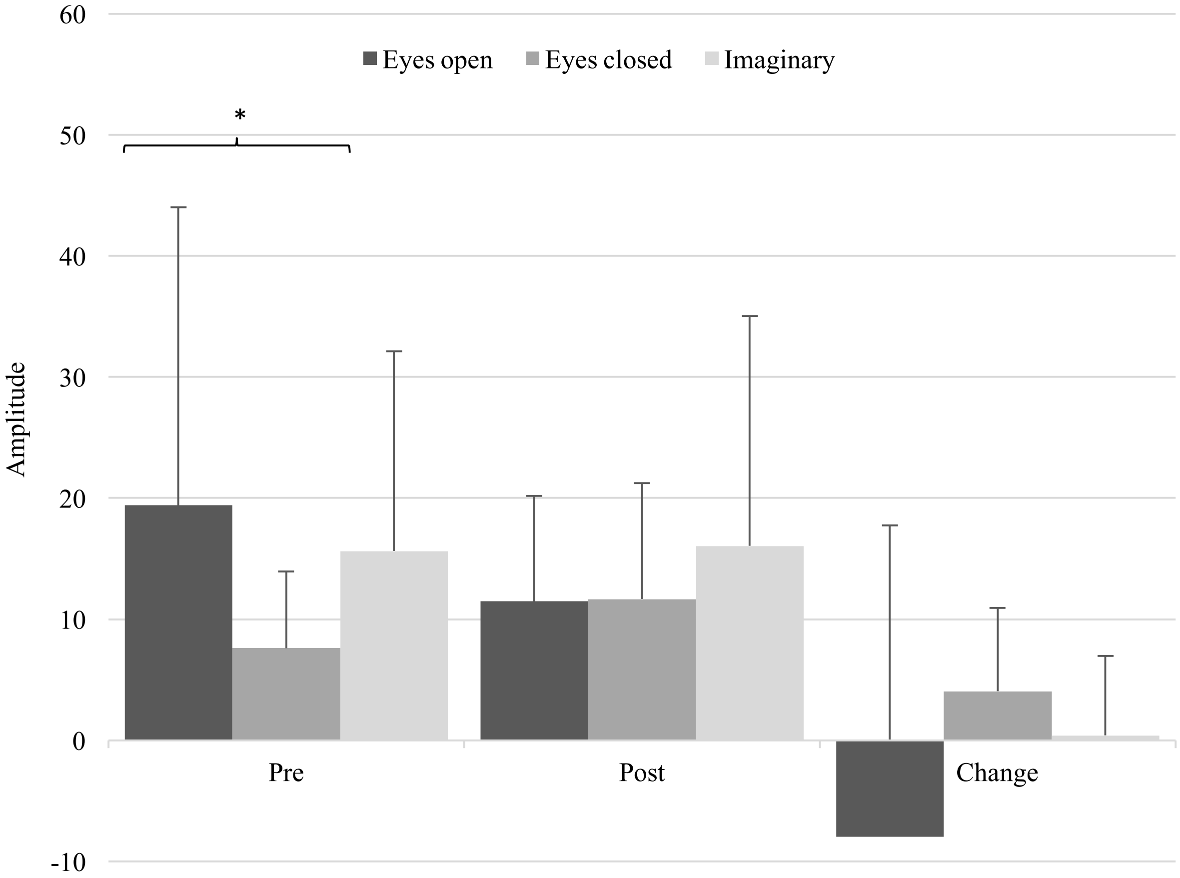

FIGURE 19. SICI values pre, post and absolute changes, standard deviations and statistical significances in eyes open, eyes closed and imaginary training conditions.
* $p < 0.05$

In eyes closed condition, SICI pre correlated with AUC change from pre to post (*$r=-0.709$, $p<0.05$, $n=10$*) and in imaginary training condition SICI change and AUC pre (*$r=-0.673$,* *p<0.05, n=10*). Other correlations were not found between SICI and AUC variables in the present study. SICI values did not correlate with motor training development values inside specific training conditions. Eyes open and imaginary training conditions I/O curve intensity changes from pre to post had zero correlations between SICI pre, post, or change values, but eyes closed condition had three. These correlations were between I/O curve intensity change 120 % (*r=-0.685, p<0.05, n=10*) between SICI pre, and intensity changes 120 % (*r=-0.733, p<0.05, n=10*) and 150 % (*r=-0.661, p<0.05, n=10*) between SICI post.

5.3 Electrical Stimulation Variables

The present study included two separate electrical stimulation variables. Table 3 shows the max M-wave, the maximal H-reflex amplitude in absolute values, and the H/M relation. The training did not have a significant effect on max M-wave and max H-reflex and differences were also not observed between training conditions.

TABLE 3. Separate motor skill training conditions and their measured maximal H-reflex (mV), maximal M-wave (mV), H/M relation, their changes from pre to post and standard deviations.

		Eyes open	**Eyes closed**	**Imaginary**
Max H-reflex (mV)	Pre	0.210 (±0.26)	0.637 (±1.18)	0.507 (±0.94)
	Post	0.246 (±0.37)	0.603 (±1.10)	0.584 (±1.14)
	Change	0.036 (±0.19)	-0.034 (±0.12)	0.077 (±0.26)
Max M-wave (mV)	Pre	5.425 (±3.67)	6.731 (±3.92)	7.139 (±3.64)
	Post	5.739 (±3.11)	6.951 (±4.50)	7.364 (±3.55)
	Change	0.314 (±1.19)	0.220 (±0.95)	0.225 (±0.42)
H/M relation	Pre	0.049 (±0.06)	0.079 (±0.10)	0.059 (±0.07)
	Post	0.044 (±0.06)	0.067 (±0.09)	0.065 (±0.08)
	Change	-0.004 (±0.03)	-0.012 (±0.02)	0.006 (±0.03)

Imaginary training condition showed indications of the biggest change in max H-reflex, but the change was not significant compared to max H-reflex changes in eyes open or closed condition. No statistical significance was found from H/M changes, but there was an indication of an increase in imaginary training. However, no correlations between motor skill training development and H/M absolute changes were found.

5.4 The Proprioception Test

There were indications of positive changes in the proprioception test in eyes open training condition but not in eyes closed or imaginary training conditions (table 4), but these changes were not significant. Instead, a statistically significant difference was found between the pre values of eyes open and imaginary training conditions ($p<0.05$). Statistical significance was not observed from proprioception developments between angular difference of pre and post. Any correlations between proprioception development and MIQ-3 points or motor training development was not found. Proprioception pre, post or angular development did not correlate with SICI absolute changes. Anyway, proprioception eyes open development correlated with SICI eyes open post ($r=0.855, p<0.002, n=10$). In the eyes closed and imaginary training conditions, correlations between proprioception development and SICI was not found.

TABLE 4. Proprioception tests averaged angular error from target angle (°), absolute change from pre to post and standard deviation in pre and post eyes open, eyes closed and imaginary training conditions.

		Eyes open	**Eyes closed**	**Imaginary training**
Error (°) and STD	Pre	12.54 (±4.85)	9.72 (±5.61)	7.13 (±3.49)
	Post	9.62 (±6.11)	10.21 (±6.98)	7.73 (±2.69)
Development (°)		2.91 (±5.11)	-0.48 (±5.41)	-0.60 (±4.49)

5.5 The Complementary Measurements

Table 5 shows the absolute value changes in measured MVC and RFD. To explain, a negative change in MVC means smaller peak forces in post compared to pre values, and a negative change in time to peak MVC indicates an improvement in the time of peak force production. MVC results show indications of a decrease in every training condition. Indications of positive change in RFD were only observed in eyes open condition. Nonetheless, these MVC and RDF changes were not significant, except in the RFD decrease in the imaginary training condition (*$p<0.05$*).

TABLE 5. Separate motor skill training conditions and their measured pre and post MVC (Nm), contraction time as time to MVC peak force (s) and RFD (Nm/s) results with standard deviations and absolute changes between pre and post.

Condition	**Eyes open**	**Eyes closed**	**Imaginary**
		MVC (Nm)	
Pre	45.34 (±8.88)	46.27 (±9.66)	44.84 (±9.57)
Post	44.28 (±8.63)	44.09 (±10.55)	42.85 (±10.48)
Change	-1.07 (±3.02)	-2.18 (±5.72)	-1.99 (±2.94)
		Time to MVC peak F (s)	
Pre	0.45 (±0.14)	0.45 (±0.15)	0.40 (±0.11)
Post	0.43 (±0.11)	0.42 (±0.10)	0.46 (±0.15)
Change	-0.02 (±0.17)	-0.03 (±0.41)	0.07 (±0.15)
		RFD (Nm/s)	
Pre	108.21 (±33.76)	109.53 (±36.65)	117.64 (±32.38)
Post	111.51 (±36.69)	108.85 (±30.79)	97.74 (±26.14)
Change	3.30 (±36.30)	-0.69 (±41.67)	-19.90 (±26.33) *

* $p < 0.05$

MIQ-3 was tested first with every subject and the questionnaire included internal, external, and kinesthetic sections. Table 6 shows the subjects' averaged points and standard errors from every section and combined points. The averaged value of the subjective rate of success was 75,95 (± 22,807) %. Internal, external, and kinesthetic points did not differ significantly from another.

From MIQ-3 values, a significant correlation was found between kinesthetic points and SICI imaginary training pre and post values (*pre* $r=-0.677$, $p<0.05$, $n=10$; *post* $r=-0.800$, $p<0.01$, $n=10$). A significant correlation was also found from proprioception eyes closed angular development and subjects subjective rate of success in imaginary training ($r=-0.799$, $p<0.01$, $n=10$). The Subjective rate of success correlated with five eyes open I/O curve intensity changes. These intensities were 110 % ($r=0.738$, $p<0.05$, $n=10$), 120 % ($r=0.671$, $p<0.05$, $n=10$), 130 % ($r=0.640$, $p<0.05$, $n=10$), 140 % ($r=0.695$, $p<0.05$, $n=10$), and 150 % ($r=0.671$, $p<0.05$, $n=10$). Kinesthetic MIQ-3 error points had also a correlation with eyes open RP error points ($r=0.659$, $p<0.05$, $n=10$).

TABLE 6. MIQ-3 test results & standard deviations averaged between subjects.

MIQ-3 part	**Internal**	**External**	**Kinesthetic**	**Combined**
Average points	5.025	5.500	5.575	16.100
STD	1.250	1.087	1.167	2.846

6 DISCUSSION

The purpose of this study was to explore how transient visual deprivation protocol impacts the learning of complex motor skills and acute cortical excitability. Both Leon-Sarmiento et al. (2005) and Castro (2015) have illustrated studies related to visual deprivation and cortical excitability. According to Leon-Sarmiento et al. (2005) study, 30 minutes of blindfolding was seen to affect corticospinal excitability levels and intracortical inhibition. Similarly to Leon-Sarmiento et al. (2005) and Castro's (2015) studies, the purpose of this study was to explain the excitability changes in the motor skill learning and from acute change point of view. The excitability changes were researched with both eyes open and eyes closed during motor skill training.

In this study, an imaginary training condition was set up to act as a reference for higher-level changes in the corticospinal tract when subjects closed their eyes. When the motor skill training was assessed, one hypothesis was that visual sense is important in skill learning but transient visual deprivation can still enhance training through separate pathways. It was also hypothesized that when the visual sense is transiently deprived, proprioception arises as a more declarative factor when performing motor skill training. It has been demonstrated that corticospinal excitability is improved when eyes are closed (Leon-Sarmiento et al. 2005), therefore this study needed a constant variable for closing eyes during motor skill training. As a result, an imaginary training condition was added to assess the effect of closing eyes and training without actual physical movement. Therefore, this study focused on exploring how transient visual deprivation affects during skilled motor performance and the role of imaginary training, and the overall role of proprioception in motor skill learning.

Contrary to hypothesized, transient visual deprivation did not show actual signs of enhancement in motor skill learning compared to training performed eyes open. However, training performed with transient visual deprivation protocol showed indications of decreased intracortical inhibition, positive level of proprioception, and increase in corticospinal excitability. Also, the rhythm phase of motor skill training showed promising changes after training performed with transient visual deprivation. However, these indications remain to be proven statistically.

The most noticeable findings in this study were the changes in motor skill training and cortical excitability. The most successful training development in total and FP was observed after eyes open training. In the rhythm part, the imaginary training condition showed promising development, but this was not statistically proven. AUC results showed that the imaginary training increased the cortical excitability significantly and indications of excitability increase after eyes closed training was also observed. Even though the results were not statistically significant, the absolute results showed indications of imaginary training increasing the excitability in every intensity and also in the spinal level, and that training performed with transient visual deprivation indicated to decrease the inhibition. Lastly, indications of proprioceptive feedback processing increase after subjects performed eyes open training was demonstrated, but the increases were not significant. An interesting finding was the base values of the proprioception test, as imaginary training condition had significantly preferable results than eyes open condition.

In eyes open training condition, the development was significant in every part, and eyes closed condition showed significant development in total and FP. Imaginary training condition did not show significant development, even though the absolute results indicated imaginary training having the best impact on RP. Additionally, this study found out that in trials 31-40 total and FP error points there was a significant difference between eyes open and imaginary training condition, and the development difference in total and FP were significant between these training conditions. The difference was not observed between eyes closed training condition and imaginary training condition. This finding may indicate that these two conditions had the same level of difficulty throughout the training. It should be noted that the subjects' results in motor skill training varied.

The reason why imaginary training did not indicate improvement as well in motor skill training total error points can be perhaps explained with the lack of proprioceptive feedback. It is said that physical motor execution provides peripheral information that lacks in motor imagery (Gentili & Papaxanthis 2015). While both training conditions can improve motor performance, Gentili & Papaxanthis (2015) finding of a quantitative difference between physical and imagery training after 60 trials indicates physical training resulting to larger learning outcome, which was in line with the results of the present study. Motor imagery training might not process the proprioceptive information as motor execution does. Also, one part that requires actual motor practice is the speed component. Imaginary training might substitute actual physically executed complex motor skill learning on some level. For example, it has been demonstrated that in imaginary training accuracy can be learned but the speed of performance is more difficult to obtain. (Sobierajewicz et al. 2016.)

Even with the lack of statistical significance, the results in this study suggested that with imaginary training the RP phase which demands rhythm components is more likely to be obtained. On the other hand, speed control which is highly required in the FP showed a lack of development after imaginary training. The target wave required speed control in various parts, but an indication of difference was observed between development in FP and RP. The parts have a specific emphasis on learning demands, which might be achieved differently by imaginary training. Sobierajewicz et al. (2016) results showed mental imagery having a beneficial impact especially on the accuracy of motor skill, while speed development requires more actual physical practice. This thought aligns with the results of this study, where especially speed requiring FP showed increases after eyes open and eyes closed training but lacked after imaginary training. Eyes open and eyes closed motor skill training developed in total and FP. This makes imaginary training learning separate from these two conditions due to imaginary training did not result in any significant developments. Additionally, the results suggest that visual sense might have a crucial role in motor skill development in all components of the present motor task.

The different possibilities obtaining speed or accuracy components, athletic training could benefit from imaginary training. A sport demanding rhythms and force control could benefit from transient visual deprivation in addition to normal eyes open training. Clearly, the results of this study indicate possibilities that transient visual deprivation could be used in athletic training which demands rhythms as evident part of the sport performance. This type of method could be used as accessory technique control while the daily training is certainly performed eyes open. It could give insights into athletes' kinesthetic and proprioceptive feedback processing and improve athletes' self-interpretation of quality training.

One of the most interesting findings in this study was found in RP development, where imaginary training showed indications of the most promising changes, even though these indications were not statistically significant. One arising thought is that the different training conditions might have an unequal emphasis on training phases such as rhythmic or force parts. Even without statistical significance, imaginary training seemed to have an affection for skill acquiring in rhythms but not as much in force control. This being said, a crucial question arises whether training conditions with different visual and motor emphasis could happen through separate skill acquiring or consolidation pathways. Stippich et al. (2002) showed supportive results of separate activations between motor imagery and motor execution. It seems, that motor imagery activates more rostral parts of the precentral gyrus, which greatly relates to premotor areas, while motor execution activates more the dorsal side of the precentral gyrus. This latter part is commonly involved with somatosensory feedback and motor output. While motor imagery and motor execution activates separate parts, Stippich et al. (2002) also suggested that these activities share functional circuits. This being said, there might be separate anatomical structures that react specifically to the type of training, but probably due to the connectivity of cortical structures, the functionality lies somewhat overlapped.

Even though I/O curve intensity changes were not all significant, there were indications of excitability changes. Taking a closer look at absolute MEP changes presented numerically and excluding the intensity of 105 % where eyes closed seemed to have the most positive MEP change, imaginary training condition had indications of the largest MEP changes from pre to post in all intensities compared to the other training conditions. Indications of the smallest or the most negative changes in intensities 105, 110, 120, 130, and 150 % was observed in eyes open condition. In intensities 90, 100, and 140 %, the smallest or the most negative change indicated to be in eyes closed condition. This might stand for that the plastic excitability change in the corticospinal tract might be the greatest in the imaginary training condition. After all, it is known that visual information affects somatosensory signal processing and motor activity in the cortical regions (Baker et al. 1999; Taylor-Clarke et al. 2002). This is seen also in the present study where eyes open condition indicated to have the most positive change in motor skill training. There are multiple components of corticospinal volleys affecting I/O curve parameters and shape, which makes it as a reflection of many descending volleys of these structures (Devanne et al. 1997).

The slope of I/O curves observed empirically raised a thought about cortical excitability changes even though the slope was not a field of interest in this study. Perez et al. (2004) found an increase in the I/O curve slope, which might indicate changes in the cortical neurons that owns a higher threshold to TMS. This can be explained through an expansion of representation areas of TA muscle at the motor cortex level (Perez et al. 2004). Additionally, Perez et al. (2004) study found a significant effect in 32-minute motor skill training, which are in line with the significant developments after 20-minute training of the present study. The changes between conditions might be due to the proprioceptive inputs to the CNS, corticospinal volleys inhibitory components increase, the number of alpha motoneurons recruited despite the maximal effort, or the inhibitory inputs of polysynaptic connections of motoneurons activated via TMS (Sekiguchi et al. 2003; Obata et al. 2009). Rosenkranz et al. (2007b) concluded, that usually improvements in the initial performance are related to synaptic connections efficacy in the already existing synapses.

When I/O curves were analysed as the area under the curve, the largest excitability change was observed in imaginary training. The change from pre to post was (+36 %) and distinctly seen while in other training conditions' changes were non-significant. This reflects the excitability change difference between training conditions. The Imaginary training increase was nearly seven times higher than another positive change observed in the eyes closed condition. Therefore, it is reasonable to conclude that this type of training induces the greatest and most significant excitability increase in the cortical area. Kumru et al. (2008) presented results that are similar to the present study. In their study, imagining motor actions itself enhanced corticospinal excitability and decreases intracortical inhibition (Kumru et al. 2008).

The overall inhibition results did not show statistical significance across training conditions or inhibition changes. Even though, there were indications of inhibition level decreasing in motor skill training conditions where visual input was transiently off. Eyes open training indicated an increase in the inhibition. One interesting finding in this study was the indication of the largest inhibition decrease observed after training performed eyes closed. Indication of inhibition decrease was observed also in imaginary training condition. These indications of absolute changes are in line with the thought that transient visual deprivation and imagining movements decrease inhibition, and that motor skill training has a reducing or removing impact on cortical inhibition levels (Perez et al. 2004; Rosenkranz et al. 2007b; Kumru et al. 2008). Especially motor skill training without a dominant visual sense, like transient visual training protocols in the present study. Also, Leon-Sarmiento et al (2005) reported decreased inhibition during blindfolding compared to eyes open condition.

In this study, the absolute values of inhibition pointed out that imaginary training indicated to have the largest values in the post and the second largest value in pre measurements. On the other hand, eyes closed training indicated to decrease inhibition the most. These inhibition results showed a lack of statistical significance. From these comparisons between training conditions, only eyes open and eyes closed pre values had a significant difference. According to Perez et al. (2004) study, inhibition of TA leg area demonstrated to decrease after motor skill training of 32 minutes, whereas the I/O curve was demonstrated to increase. The change was not found in the non-skill or passive condition. This reflects that the motor cortical excitability change happens after a specific type of motor skill training. (Perez et al. 2004.) The present study showed similarities with indications of the inhibition and the I/O curve excitability changes after 20 minutes of TA motor skill training. Perez et al. (2004) also studied the TA I/O curve with transcranial electrical stimulation (TES). Based on their results, the excitability changes occurred more likely at the cortical site. Therefore, they concluded that motor skill task difficulty requirement has a role in the level of plasticity changes appearance. (Perez et al. 2004.) The present study results might be explained with this task difficulty requirements. Imaginary training might require more attention and conscious processing making eyes closed training easier and more sensitive to inhibitory plastic changes.

The electrical stimulation variables maximal M-wave and H-reflex, maximal M-wave represents maximal direct motor response and supramaximal electrical stimulated motor axons (Yavuz et al. 2018; Frigon et al. 2007). In other words, maximal M-wave represents every motoneuron activating on the specific muscle of interest (Palmieri et al. 2004). The maximal M-wave amplitudes did not have statistically significant changes across training conditions in pre, post, or absolute change, which was anticipated. In order to compare results, maximal M-wave was measured as a stimulus constancy variable. In the present study, a maximal H-reflex was analysed in relation to maximal M-wave as a reflector of the spinal pathways and the spinal level excitability (Taube et al. 2006). The reflex was also used as an indicator of specific alpha motoneuronal pool excitability (Palmieri et al. 2002). An increase in reflex amplitude can be explained through inhibition decrease in Ia afferent level by spinal drive change (Taube et al. 2006). Comparing the H-reflexes is dependent on e.g. muscle EMG activity, head or body posture, eyes open or closed, or electrode placement (Schieppati 1987; Kameyama et al. 1989; Funase & Miles 1999). As mentioned above, these noteworthy variables were used in this study to reassure constant and stable recording conditions.

Separate motor skill training conditions did not have statistically significant effect on H/M relation. The only training that indicated a slight spinal excitability change was the imaginary training. This might reflect possible positive changes in alpha motoneuronal pool excitement, reflex pathway, or synaptic transmission efficacy level. As an example, Hale et al. (2003) demonstrated in their study that motor task imagery might influence H-reflex. It is thought that imaginary training practice alters H-reflex more than the intensity of the task performed imaginary. (Hale et al. 2003.) This study did not control the subjects' execution plan of imaginary training. This was since a controlled imaginary training protocol might alter the level of difficulty. This could consequently affect negatively on achieving the development already in multifold and many skills-required task.

It has been concluded that imagery training has a positive effect on motor training (Lotze & Halsband 2006). The reason why it affects positively could be explained with the fact that imagining motor movements activate and modulate corticospinal tract excitability (Kumru et al. 2008; Grospretre et al. 2016). Kumru et al. (2008) pointed out that imagining action might enhance corticospinal motor pathway excitability. A possibility is also in the reduction of intracortical inhibition of the motor cortex (Kumru et al. 2008). One of the possible reasons might be in this more inferior inhibition levels before and after imaginary training rather than eyes closed training.

The purpose of the present study was to clarify the role of proprioception in motor skill learning. The IJPR test strives to complete isolation in a way of proprioceptive sense (Han et al. 2016). Other influencing factors were reduced as much as possible. There are some theory suggestions behind the IJPR test. These theories highlight that the passive motion strikes out an active motion-related fusimotor activity and sensory feedback from spindles. On the other hand, passive motion provides a chance for cutaneous receptor inputs as sensory feedback feature. The sampling rate of IJPR test reproduction influences the attention level and test results. (Han et al. 2016.)

As mentioned earlier, it has been suggested that sensorimotor training improves proprioceptive afferent feedback processing (Gandevia 2001). This enhances the neuromuscular activation of the training muscles (Gandevia 2001). One significant difference was found from the proprioception results, which was between eyes open and imaginary training pre proprioception test values. However, there were indications that proprioception has a role in fine motor skill learning. Even though other results were not significant, there were indications of imaginary training pre and post having the lower scores compared to other conditions. Eyes open training indicated to induce the most change in proprioceptive enhancement. It should be noted that in this study, the proprioception test scores the lowest points are seen as the most positive ones. This is due to the scores are error points from the target angle of the test. As eyes open training indicated to have the most positive change in the proprioception test, it is reasonable to point that vision has a dominant role over the other senses (Brodoehl et al. 2015). Visual input has a major impact on motor performance, and in this study proprioception test had high requirements of the memory system and attention (Perez et al. 2004; Han et al. 2016). Evidence highlight how the cerebellum plays a crucial role in motor learning, especially learning that claims error-based processing like the present study (Spampinato et al. 2017). In this type of processing, systematic errors are compensated at the cortical level (Spampinato et al. 2017).

Even without statistical significance, a fascinating indication in this study was that the imaginary training indicated to have the lowest error points from pre and post proprioception tests, it also suggested to have the lowest in standard deviations. Brodoehl et al. (2015) conclude that already closing eyes have an effect on the perception of sensory systems. These proprioception test indications might be one possible explanation in this study. Rapid and transient motor training may induce representation area plasticity-like effects reflecting also short-term memory for movement, which could be thought of as an equivalent part of skill acquisition (Classen et al. 1998).

The subjects' imaginary training skills were measured by using Williams et al. (2012) version of Movement Imagery Questionnaire – 3 from Hall & Pongrac (1983). The questionnaire measured the subjects' individual ability to perform internal, external, and kinesthetic imaginary through separate movements. When the questionnaire was rated for each subject and averaged per MIQ-3 perspective, the results showed indications that kinesthetic imagery might be the easiest way to practice imaginary training whereas the hardest perspective indicated to be internal imagery. Unfortunately, these were not backed up by statistics. The kinesthetic perspective is described by the feeling of itself when performing the movement without any actual physical movement (Williams et al. 2012). Kinesthetic imagery is also thought to facilitate motor learning by activating the motor system (Grospretre et al. 2016). The MIQ-3 results can be affected by the subjects who had a strong physically active background. Motor imagery is often used as a part of the training session, especially in sports that are perceived as risky disciplines (Lotze & Halsband 2006). These sports may include e.g. snowboarding, gymnastics, and figure skating. In this study, some of the subjects had experience from these sports.

In the following text, the complementary tests are discussed. In this study, the force measurements were added to the research plan because of the possibility of training induced force gain and fatigue. Also, testing of force was perceived as a suitable measurement because the target wave in motor skill training included maximal contraction per trial. The training did not have statistical effect on MVC, but indications of decreases were observed in all training conditions. These results might indicate muscle fatigue as a result of the motor skill training having only 20 second feedback time. This time as a resting and feedback period still required conscious processing. In order to avoid boredom, the feedback period was assessed to be only 20 seconds. This fatigue can affect the descending drive from superior centres, which affects contractile properties (Enoka & Stuart 1992). As the task theme consisted of force and rhythmic compartments, neural fatigue can arise through task dependency, force-fatigability relationship, muscle wisdom, or sense of effort determining performance effort (Enoka & Stuart 1992). There also might be an altering effect on motivation because of the level of difficulty and time. Therefore, performance duration and level of motivation are explaining factors of fatigue (Enoka & Stuart 1992).

In Gruber and Gollhofer (2004) study, sensorimotor training was concluded to impact force production through neuromuscular system alteration. The proprioception test and motor training in this study might represent a form of sensorimotor training method, which could be the reason for the indications in RFD in training conditions. One significant change was observed from all force measurements, which was RFD decrease in imaginary training. This might be due to the lack of training of speed properties, which was present in eyes open and eyes closed training. However, eyes open condition indicated a positive change in RFD, which might result from the enhancement in explosive strength and voluntary onset for neuromuscular activation (Gruber & Gollhofer 2004). Alterations in neuromuscular activation include recruitment and firing frequency changes in the motoneuronal level (Aagaard et al. 2002b). Adaptations in motor unit firing frequency or recruitment have been demonstrated to be probable cause in RFD increase mainly due to resistance training (Holtermann et al. 2007).

To combine the earlier discussion and even though there was a lack of statistical support, one thought to remember is that while the indications of the largest positive change in proprioception were observed in eyes open condition, imaginary training had a significantly better starting level and indications of better post results. Representation area expansion might explain this short-term plasticity effect resulting from test-like rapid and transient training, such as Classen et al. (1998) reported. This links also with I/O curve results, where imaginary training showed indications of increased excitability of the corticospinal tract throughout every intensity. Imaginary training having a significant excitability change in AUC supports these indications. The significant change in imaginary training 120 % might reflect higher threshold neurons excitability change and indicate the expansion of this representation area of the muscle used (Perez et al. 2004). In addition to possible representation area expansion, the I/O curve excitability increase, and the indication of H/M relation result suggests plastic changes also in the spinal tract.

The inhibition results indicate that transient visual deprivation has an effect on inhibition levels when considering the observed correlations between eyes closed and imaginary training SICI and AUC. Overall, literature concludes that attention is an important component of the learning process (Wulf et al. 2010). External focus is thought to be an effective component directing the attention when thinking about movement performance and learning (Wulf et a. 2010). This kind of external focus could be e.g. pedal of the dynamometer during the performance of proprioception test or motor skill training. External focus relates to the speeding of the learning by promoting the automaticity of movement (Wulf et al. 2010). This kind of external focus might be a factor that showed in eyes closed training and lacked in imaginary training.

The results combined arises a thought concerning probable non-visual promoted processing like in eyes closed or imaginary training conditions driven strategies of learning. These altered strategies of learning might arise from somatosensory influenced cortical networks (Brodoehl et al. 2015). This processing could result from a change between cortical level performance or learned focused attention (Brodoehl et al. 2015). It can be speculated that the change in attention is affecting motor skill learning conditions. Having said that, when comparing the indications of training error point changes with exploiting the possibility of decreased inhibition or spinal adaptations, there remains a question related to the difference of aroused excitability change between transient visual deprivation protocols. It also remains unsolved whether the showed indications of differences between these transient visual deprivation protocols are since the other showed indications of a decrease in the intracortical inhibition and other owned considerably preferable proprioceptive processing base values compared to eyes open condition.

In the I/O curve, imaginary training excitability change was significant. This links up with inhibition results, where indications of decreased inhibition were observed in both transient visual deprivation protocols, and imaginary training showed indications of spinal level excitability change in addition to indications of the most preferable proprioception processing. Even without statistical significance, these imaginary training induced indications might explain the positive outcome in the larger I/O curve excitability compared to other training conditions.

When combining the discussion of motor skill training, one reason for the indication of imaginary training induced learning in rhythm and accuracy are the significant corticospinal excitability possibly through the reflex pathways, proprioceptive feedback processing, and decreased intracortical inhibition. Even though the intracortical inhibition showed indications of an increase in eyes open condition, proprioception processing pre value was still significantly less than imaginary training. From post, the significant difference was not observed. Therefore, is reasonable to discuss that the notable development in motor skill training with vision might happen through proprioceptive pathways rather than decreasing intracortical inhibition. When vision is enabled during motor skill training even though it is focused away from the training limb, it might be a more familiar setting to arouse proprioceptive processing compared to transient visual deprivation protocols.

Imaginary training showed indications of an impact on RP, while eyes open and eyes closed training effect in FP and total error points were significant. Development in transient visual deprivation combined with actual physical movement enhanced more FP possibly through repetitions of force and speed production, decreased inhibition, and excitability increase. One possible explanation is that motor skill training induced fatigue in high threshold fast and fatigable motor units decreased the corticospinal excitability in high intensities. It can be concluded that in the present study, the motor skill training intervention seemed to be the most suitable for eyes open training where the subjects were able to use their dominant sense of vision.

The limitations to be discussed, the study provided interesting results concerning transient visual deprivation and motor skill training development with an additional proprioceptive standpoint. Some limitations should be considered when combining proprioceptive effects and motor skill training with transient visual deprivation protocols. One clear thing to discuss is TMS reliability. The obtainable technical equipment did not include the TMS mapping technique, which could have offered more insights for the present research plan. Also, combining larger neurophysiological research methods to assess the mechanisms of fatigue could have given more elaborating results about cellular and neural fatigue effects. A limitation concerning the motor skill training and attention, EEG could have given refining results about the focused attention during specific and separate motor skill learnings. Therefore, it is suggested that the study plan could be promoted with the EEG technique in the future. While the present study had an imaginary training protocol freely selected by the specific subject, EEG could have given more insights about the attention driven learning when a specific imaginary training protocol to perform is instructed to every subject. This could be one point of view for possible future research in this context.

Possible future research could strive for a larger sample size. This would exclude the dispersion of results seen clearly in standard deviations of the proprioception results and provide more statistical significance. Possibly due to the sample size, some of the results didn’t reach the level of significance hoped, but there were indications that transient visual deprivation during motor skill training might be beneficial for someone in different ways. It also would have been beneficial if every subject would have participated in one motor skill training intervention and the sample size would have profited over ten subjects in every intervention protocol. Due to the complexity of gaining a homogeneous subject sample, the present study set the subjects as their own reference when they all completed all of the three different motor skill training interventions. A larger and more homogenous sample size without athletic history might also give differing results from the MIQ-3.

One field of interest in transient visual deprivation and skill learning is longer training periods. The present study assessed the acute excitability changes, which would be interesting to compare with chronic adaptations and plasticity effects induced with multiple session skill training protocol. The emphasis of transient visual training protocols induced plasticity effects and processing might have evolved to more physiological alterations. These might be different neural tissue geneses instead of potentiation or excitability change in existing synapses. Another interesting research question is what might happen to these analysed distinct differences between eyes closed and imaginary training induced effects after a longer training period. In addition, would have been interesting to know is there any possible explanations lying in the attention, or the body periphery related kinesthetic imagery.

In conclusion, the main result of this study is that all main variables had correlations and pathways affecting each other. Proprioception was one of the main objects to study, and motor skill training was the intervention. Above all, vision acted as a meaningful and restrictive variable. To conclude, it seems that sensorimotor training has an increasing effect on the motor skill learning process through possible excitability changes and its correlations with inhibition alterations. Also, there are indications of associated proprioception feedback processing. The main outcome is that vision is a dominant sense in motor skill learning. With vision deprived, compensatory learning mechanisms might arise from increased corticospinal excitability and decreased intracortical inhibition. The initial performance related excitability change happens possibly through efficacy change in already existing synapses connections and inhibitory alterations (Jacobs & Donoghue 1991; Kleim et al. 2004; Rosenkranz et al. 2007b). Although these results support each other, it must be recognized that there were indications of transient visual deprivation affecting the proprioception scores. Imaginary training as a training condition without visual feedback showed significantly better pre values in the proprioception test compared to eyes open condition. The reason why proprioception scores showed stabilization after training and how it affects between transient visual deprivation protocols remains unanswered.

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REFERENCES

Aagaard, P., Simonsen, E. B., Andersen, J. L., Magnusson, P. & Dyhre-Poulsen P. 2002a. Neural adaptation to resistance training: changes in evoked V-wave and H-reflex responses. Journal of Applied Physiology 92: 2309-2318.

Aagaard, P., Simonsen, E. B., Andersen, J. L., Magnusson, P. & Dyhre-Poulsen, P. 2002b. Increased rate of force development and neural drive of human skeletal muscle following resistance training. Journal of Applied Physiology 93: 131-1326.

Adkins, D. L., Boychuk, J., Remple, M. S. & Kleim, J. A. 2006. Motor training induces experience-specific patterns of plasticity across motor cortex and spinal cord. Journal of Applied Physiology 101: 1776-1782.

Altman, J. & Das, G. D. 1965. Autoradiographic and histological evidence of postnatal hippocampal neurogenesis in rats. The Journal of Comparative Neurology 124(3): 319-335.

Amaral, D. G. 2000. The Anatomical Organization of the Central Nervous System. In Kandel, E. R., Schwartz, J. H. & Jessell, T. M. (eds.). Principles of Neural Science. 4th edition. USA: McGraw-Hill Companies.

Ashton-Miller, J. A., Wojtys, E. M., Huston, L. J. & Fry-Welch D. 2001. Can proprioception really be improved by exercises? Knee Surgery, Sports Traumatology, Arthroscopy 9: 128-136.

Avela, J. & Gruber, M. 2011. Transcranial magnetic stimulation as a tool to study the role of the motor cortex in human muscle function. In Komi, P. V. (edit.). Neuromuscular Aspects of Sports Performance. 1st edition. UK: A John Wiley & Sons Ltd.

Awiszus, F. & Borckardt, J. J. (n.d.). TMS Motor Threshold Assessment Tool 2.0.

Bachtiar, V., Johnstone, A., Berrington, A., Lemke, C., Johansen-Berg, H., Emir, U. & Stagg, C. J. 2018. Modulating Regional Motor Cortical Excitability with Noninvasive Brain Stimulation Results in Neurochemical Changes in Bilateral Motor Cortices. The Journal of Neuroscience 38(33): 7327-7336.

Baker, J. T., Donoghue, J. P. & Sanes, J. N. 1999. Gaze direction modulates finger movement activation patterns in human cerebral cortex. Journal of Neuroscience 19: 10044-10052.

Beaulieu, L. D., Massé-Alarie, H., Brouwer, B. & Schneider, C. 2014. Brain control of volitional ankle tasks in people with chronic stroke and in healthy individuals. Journal of the Neurological Sciences 228: 148-155.

Beck, S. Taube, W., Gruber, M., Amtage, F., Gollhofer, A. & Schubert, M. 2007. Task-specific changes in motor evoked potentials of lower limb muscles after different training interventions. Brain Research 1179: 51-60.

Ben-Simon, E., Podlipsky, I. Okon-Singer, H., Gruberger, M., Cvetkovic, D., Intrator, N. & Hendler, T. 2013. The dark side of the alpha rhythm: fMRI evidence for induced alpha modulation during complete darkness. European Journal of Neuroscience 37: 795-803.

Borckardt, J. J., Nahas, Z., Koola, J. & George M. S. 2006. Estimating Resting Motor Thresholds in Transcranial Magnetic Stimulation Research and Practice: A computer Stimulation Evaluation of Best Methods. The Journal of ECT 22: 169-175.

Brodoehl, S., Klinger, C. M. & Witte, O. W. 2015. Eye closure enhances dark night perceptions. Scientific Reports 5: 1-10.

Brooke, J. D., McIllroy, W. E., Miklic, M., Staines, W. R., Misiaszek, J. E., Peritore, G. & Angerilli, P. 1997. Modulation of H reflexes in human tibialis anterior muscle with passive movement. Brain Research 766: 236-239.

Canedo, A. 1997. Primary motor cortex influences on the descending and ascending systems. Progress in Neurobiology 51: 287-335.

Cantarero, G., Lloyd, A. & Celnik, P. 2013. Reversal of Long-Term Potentiation-Like Plasticity Processes after Motor Learning Disrupts Skill Retention. The Journal of Neuroscience 33(31): 12862-12869.

Carel, C., Loubinoux, I., Boulanouar, K., Manelfe, C., Rascol, O., Celsis, P. & Chollet, F. 2000. Neural Substrate for the Effects of Passive Training on Sensorimotor Cortical Representation: A Study With Functional Magnetic Resonance Imaging in Healthy Subjects. Journal of Cerebral Blood Flow and Metabolsim 20: 478-484.

Carroll, T. J., Riek, S. & Carson, R. G. 2001. Neural Adaptations to Resistance Training. Sports Medicine 31(12): 829-840.

Cash, R. F. H., Noda, Y., Zomorrodi, R., Radhu, N., Farzan, F., Rajji, T. K., Fitzgerald, P. B., Chen, R., Daskalakis, Z. J. & Blumberger, D. M. 2017. Characterization of Glutamatergic and GABA$_A$ –Mediated Neurotransmission in Motor and Dorsolateral

Prefrontal Cortex Using Paired Pulse TMS-EEG. Neuropsychopharmacology 42: 502-511.

Castro, F. 2015. The effect of transient visual deprivation of motor cortical excitability and motor learning. University of Jyväskylä. Department of Biology of Physical Activity. Master's Thesis in Biomechanics. Cited 20th November 2019. https://jyx.jyu.fi/bitstream/handle/123456789/51952/URN%3aNBN%3afi%3ajyu-201611224708.pdf?sequence=1&isAllowed=y

Chen, P., Cescon, M. & Bonaldo, P. 2015. The Role of Collagens in Peripheral Nerve Myelination and Function. Molecular Neurobiology 52: 216-225.

Chen, R., Tam, A., Bütefisch, C., Corwell, B., Ziemann, U., Rothwell, J. C. & Cohen, L. G. 1998. Intracortical Inhibition and Facilitation in Different Representations of the Human Motor Cortex. The Journal of Neurophysiology 80: 2870-2881.

Chen, R. & Udupa, K. 2009. Measurement and Modulation of Plasticity of the Motor System in Humans Using Transcranial Magnetic Stimulation. Motor Control 13: 442-453.

Chong, R. K. Y., Ambrose, A., Carzoli, J., Hardison, L. & Jacobson, B. 2001. Source of improvement in balance control after a training program for ankle proprioception. Perceptual and Motor Skills 92: 265-272.

Christiansen, L., Lundbye-Jensen, J., Perez, M. A. & Nielsen, J. B. 2017. How plastic are human spinal cord motor circuitries? Experimental Brain Research 235: 3243-3249.

Cirillo, J., Todd, G. & Semmler, J. G. 2011. Corticomotor excitability and plasticity following complex visuomotor training in young and old adults. European Journal of Neuroscience 34: 1847-1856.

Classen, J., Liepert, J., Wise, S. P., Hallett, M & Cohen, L. G. 1998. Rapid Plasticity of Human Cortical Movement Representation Induced by Practice. Journal of Neurophysiology 79(2): 1117-1123.

Conforto, A. B., Kaelin-Lang, A. & Cohen, L. G. 2002. Increase in hand muscle strength of stroke patients after somatosensory stimulation. Annals of Neurology 51(1): 122-125.

Cullen, C. L. & Young, K. M. 2016. How Does Transcranial Magnetic Stimulation Influence Glial Cells in the Central Nervous System? Frontiers in Neural Circuits 10(26).

Dayan, E. & Cohen, L. G. 2011. Neuroplasticity Subserving Motor Skill Learning. Neuron 72(3): 443-454.

Devanne, H., Lavoie, B. A. & Capaday, C. 1997. Input-output properties and gain changes in the human corticospinal pathway. Experimental Brain Research 114: 329-338.

Duchateau, J. & Enoka, R. M. 2008. Neural control of shortening and lengthening contractions: influence of task constraints. Journal of physiology 586(4): 5853-5864.

Duchateau, J. & Enoka, R. M. 2016. Neural control of lengthening contractions. Journal of Experimental Biology 219: 197-204.

Elsayed, G. F., Lara, A. H., Kaufman, M. T., Churchland, M. M. & Cunningham, J. P. 2016. Reorganization between preparatory and movement population responses in motor cortex. Nature Communications 7: 13239.

Enoka, R. M. & Stuart, D. G. 1992. Neurobiology of muscle fatigue. The Journal of Applied Physiology 72(5): 1631-1648.

Fields, R. D. 2015. A new mechanism of nervous system plasticity: activity dependent myelination. Nature Reviews Neuroscience 16(12): 756-767.

Fisher, R. J., Nakamura, Y., Bestmann, S., Rothwell, J. C. & Bostock H. 2002. Two phases of intracortical inhibition revealed by transcranial magnetic threshold tracking. Experimental Brain Research 143: 240-248.

Floyer-Lea, A. & Matthews, P. M. 2004. Changing Brain Networks for Visuomotor Control with Increased Movement Automaticity. Journal of Neurophysiology 92: 2405-2412.

Frigon, A., Carroll, T. J., Jones, K. E., Zehr, E. P. & Collins, D. F. 2007. Ankle Position and Voluntary Contraction Alter Maximal M Waves in Soleus and Tibialis Anterior. Muscle & Nerve 35: 756-766.

Funase, K. & Miles, T. S. 1999. Observations on the Variability of the H Reflex in Human Soleus. Muscle & Nerve 22: 341-346.

Gandevia, S. C. 2001. Spinal and Supraspinal Factors in Human Muscle Fatigue. Physiological Reviews 81(4): 1725-1789.

Gentili, R. J. & Papaxanthis, C. 2015. Laterality Effects in Motor Learning by Mental Practice in Right-Handers. Neuroscience 297: 231-242.

Gramfort, A. 2009. Mapping, timing and tracking cortical activations with MEG and EEG: Methods and application to human vision. INRIA Sophia Antipolis. PhD Thesis.

Green, C. S. & Bavelier, D. 2008. Exercising Your Brain: A Review of Human Brain Plasticity and Training-Induced Learning. Psychology and Aging 23(4): 692-701.

Groppa, S., Oliviero, A., Eisen, A., Quartarone, A., Cohen, L. G., Mall, V., Kaelin-Lang, A., Mima, A., Rossi, S., Thickbroom, G. W., Rossini, P. M., Ziemann, U., Valls-Solé, J. & Siebner, H. R., 2012. A practical guide to diagnostic transcranial magnetic stimulation: Report of an IFCN committee. Clinical Neurophysiology 123: 858-882.

Grospretre, S., Ruffino, C. & Lebon, F. 2016. Motor imagery and cortico-spinal excitability: A review. European Journal of Sport Science 16(3): 317-324.

Gruber, M. & Gollhofer, A. 2004. Impact of sensorimotor training on the rate of force development and neural activation. European Journal of Applied Physiology 92: 98-105.

Hale, B. S., Raglin, J. S. & Koceja, D. M. 2003. Effect of mental imagery of a motor task on the Hoffman reflex. Behavioural Brain Research 142: 81-87.

Hallett, M. 2000. Transcranial magnetic stimulation and the human brain. NATURE 406: 147-150.

Hallett, M. 2001. Plasticity of the human motor cortex and recovery from stroke. Brain Research Reviews 36: 169-174.

Hallett, M. 2007. Transcranial Magnetic Stimulation: A Primer. Neuron 55(2): 187-199.

Han, J., Waddington, G., Adams, R., Anson, J. & Liu, Y. 2016. Assessing proprioception: A critical review of methods. Journal of Sport and Health Science 5: 80-90.

Hirano, M., Kubota, S., Koizume, Y. & Funase, K. 2018. Acquisition of motor memory determines the interindividual variability of learning-induced plasticity in the primary motor cortex. Journal of Applied Physiology 125: 990-998.

Holtermann, A., Roeleveld, K., Vereijken, B. & Etteman G. 2007. The effect of rate of force development on maximal force production: acute and training-related aspects. European Journal of Applied Physiology 99: 605-613.

Ihunwo, A. O., Tembo, L. H. & Dzamalala, C. 2016. The dynamics of adult neurogenesis in human hippocampus. Neural Regeneration Research 11(12): 1869-1883.

Jacobs, K. M. & Donoghue, J. P. 1991. Reshaping the Cortical Motor Map by Unmasking Latent Intracortical Connections. Science 251: 944-947.

Jensen, J. L., Marstrand, P. C. D. & Nielsen, J. B. 2005. Motor skill training and strength training are associated with different plastic changes in central nervous system. Journal of Applied Physiology 99: 1558-1568.

Jonker, Z. D., van der Vliet, R., Hauwert, C. M., Gaiser, C., Tulen, J. H. M., van der Geest, J. N., Donchin, O., Ribbers, G. M., Frens, M. A. & Selles, R. W. 2019. TMS motor mapping: Comparing the absolute reliability of digital reconstruction methods to the golden standard. Brain Stimulation 12: 309-313.

Kameyama, O., Hayes, K. C. & Wolfe, D. 1989. Methodological Considerations Contributing to Variability of the Quadriceps H-reflex. American Journal of Physical Medicine & Rehabilitation 86(6): 277-282.

Kandel, E. R. 2000. Cellular Mechanisms of Learning and the Biological Basis of Individuality. In Kandel, E. R., Schwartz, J. H. & Jessell, T. M. (eds.). Principles of Neural Science. 4th edition. USA: McGraw-Hill Companies.

Kee, N., Teixeira, C. M., Wang, A. H. & Frankland, P. W. 2007. Preferential incorporation of adult-generated granule cells into spatial memory networks in the dentate gyrus. Nature Neuroscience 10: 355-362.

Keller, A. 1993. Intrinsic Synaptic Organization of the Motor Cortex. Cerebral Cortex 3: 430-441.

Kempermann, G., Gage, F. H., Aigner, L., Song, H., Curtis, M. A., Thuret, S., Kuhn, H. G., Jessberger, S., Frankland, P. W., Cameron, H. A., Gould, E., Hen, R., Abrous, D. N., Toni, N., Schinder, A. F., Zhao, X., Lucassen, P. J. & Frisén, J. 2018. Human Adult Neurogenesis: Evidence and Remaining Questions. Cell Stem Cell 23(1): 25-30.

Kempter, R., Gerstner, W. & van Hemmen, J. L. 1999. Hebbian learning and spiking neurons. Physical Review E 59(4): 4498-4514.

Kerr, A. L., Steuer, E. L., Pochtarev, V. & Swain, R. A. 2010. Angiogenesis but not neurogenesis is critical for normal learning and memory acquisition. Neuroscience 171: 214-226.

Khaslavskaia, S., Ladouceur, M. & Sinkjaer, T. 2002. Increase in tibialis anterior motor cortex excitability following repetitive electrical stimulation of the common peroneal nerve. Experimental Brain Research 145: 309-315.

Kida, H., Tsuda, Y., Ito, N., Yamamoto, Y., Owada, Y., Kamiya, Y. & Mitsushima, D. 2016. Motor Training Promotes Both Synaptic and Intrinsic Plasticity of Layer II/III Pyramidal Neurons in the Primary Motor Cortex. Cerebral Cortex 26: 3493-3507.

Kleim, J. A., Hogg, T. M., VandenBerg, P. M., Cooper, N. R., Bruneau, R. & Remple, M. 2004. Cortical Synaptogenesis and Motor Map Reorganization Occur during Late, But

Not Early, Phase of Motor Skill Learning. The Journal of Neuroscience 24(3): 628-633.

Knikou, M. 2008. The H-reflex as a probe: Pathways and pitfalls. Journal of Neuroscience Methods: 171: 1-12.

Kobayashi, M. & Pascual-Leone, A. 2003. Transcranial magnetic stimulation in neurology. Lancet Neurology 2: 145-156.

Kronberg, G., Bridi, M., Abel, T., Bikson, M. & Parra, L. C. 2017. Direct Current Stimulation Modulates LTP and LTD: Activity Dependence and Dendritic Effects. Brain Stimulation 10: 51-58.

Kujirai, T., Caramia, M. D., Rothwell, J. C., Day, B. L., Thompson, P. D., Ferbert, A., Wroe, S., Asselman, P. & Marsden, C. D. 1993. Corticocortical Inhibition in Human Motor Cortex. Journal of Physiology 471: 501-519.

Kumpulainen, S., Avela, J., Gruber, M., Bergmann, J., Voigt, M., Linnamo, V. & Mrachacz-Kersting, N. 2015. Differential modulation of motor cortex plasticity in skill- and endurance-trained athletes. European Journal of Applied Physiology 115:1107-1115.

Kumru, H., Soto, O., Casanova, J. & Valls-Sole, J. 2008. Motor cortex excitability changes during imagery of simple reaction time. Experimental Brain Research 189: 373-378.

Lauber, B., Gollhofer, A. & Taube, W. 2018. Differences in motor cortical control of the soleus and tibialis anterior. Journal of Experimental Biology 221.

Lauri, S. E., Palmer, M., Segerstrale, M., Vesikansa, A., Taira, T. & Collingridge, G. L. 2007. Presynaptic mechanisms involved in the expression of STP and LTP at CA1 synapses in the hippocampus. Neuropharmacology 52(1): 1-11.

Leon-Sarmiento, F. E., Bara-Jimenez, W. & Wassermann, E. M. 2005. Visual deprivation effects on human motor cortex excitability. Neuroscience Letters 389: 17-20.

Limanowski, J. & Blankenburg, F. 2016. Integration of Visual and Proprioceptive Limb Position Information in Human Posterior Parietal, Premotor, and Extrastriate Cortex. The Journal of Neuroscience 26(9): 2582-2589.

Lin, C-H., Winstein, C. J., Fisher, B. E. & Wu, A. D. 2010. Neural Correlates of the Contextual Interference Effect in Motor Learning: A Transcranial Magnetic Stimulation Investigation. Journal of Motor Behavior 42(4): 223-232.

Lopez-Alonso, V., Cheeran, B. & Fernández-del-Olmo, M. 2015. Relationship Between Non-invasive Brain Stimulation-induced Plasticity and Capacity for Motor Learning. Brain Stimulation 8: 1209-1219.

Lotze, M., Braun, C., Birbaumer, N., Anders, S. & Cohen, L. 2003. Motor learning elicited by voluntary drive. Brain 126: 866-872.

Lotze, M. & Halsband, U. 2006. Motor imagery. Journal of Physiology 99(4-6): 386-395.

Lu, X. & Ashe, J. 2015. Dynamic reorganization of neural activity in motor cortex during new sequence production. European Journal of Neuroscience 42: 2172-2178.

MacDonald, D. B., Skinner, S., Shils, J. & Yingling C. 2013. Intraoperative motor evoked potential monitoring – A position statement by the American Society of Neurophysiological Monitoring. Clinical Neurophysiology 124: 2291-2316.

Monfils, M-H., Plautz, E. J. & Kleim, J. A. 2005. In Search of the Motor Engram: Motor Map Plasticity as a Mechanism for Encoding Motor Experience. The Neuroscientist 11: 471-483.

Moscatelli, F., Messina, G., Valenzano, A., Monda, V., Viggiano, A., Messina, A., Petito, A., Triggiani, A. I., Ciliberti, M. A. P., Monda, M., Capranica, L. & Cibelli, G. 2016. Functional Assessment of Corticospinal System Excitability in Karate Athletes. PLOS ONE 11(7).

Mrachacz-Kersting, N. & Stevenson, A. J. T. 2017. Paired Associative Stimulation Targeting the Tibialis Anterior Muscle using either Mono or Biphasic Transcranial Magnetic Stimulation. Frontiers in Human Neuroscience 11: 197.

Munzert, J., Lorey, B. & Zentgraf, K. 2009. Cognitive motor processes: The role of motor imagery in the study of motor representations. Brain research reviews 60: 306-326.

Nelson, T. J. & Alkon, D. L. 2015. Molecular regulation of synaptogenesis during associative learning and memory. Brain Research 1621: 239-251.

Niazi, I. K., Mrachacz-Kersting, N., Jiang, N., Dremstrup, K. & Farina, D. 2012. Peripheral Electrical Stimulation Triggered by Self-Paced Detection of Motor Intention Enhances Motor Evoked Potentials. IEEE Transactions on neural Systems and Rehabilitation Engineering 20(4): 595-604.

Niazi, I. K., Türke, K. S., Flavel, S., Kinget, M., Duehr, J. & Haavik, H. 2015. Changes in H-reflex and V-waves following spinal manipulation. Experimental Brain Research 233: 1165-1173.

Nielsen, J. B. & Cohen, L. G. 2008. The Olympic brain. Does corticospinal plasticity play a role in acquisition of skills required for high-performance sports? Journal of Physiology 586(1): 65-70.

Nudo, R. J., Friel, K. M. & Delia, S. W. 2000. Role of sensory deficits in motor impairments after injury to primary motor cortex. Neuropharmacology 39: 733-742.

Obata, H., Sekiguchi, H., Nakazawa, K. & Ohtsuki, T. 2009. Enhanced excitability of the corticospinal pathway of the ankle extensor and flexor muscles during standing in humans. Experimental Brain Research 197: 207-213.

Ohura, S. & Kamiya, H. 2016. Excitability tuning of axons in the central nervous system. The Journal of Physiological Sciences 66: 189-196.

Palmieri, R. M., Hoffman, M. A. & Ingersoll, C. D. 2002. Intersession Reliability for H-reflex Measurements Arising from the Soleus, Peroneal, and Tibialis Anterior Musculature. International Journal of Neuroscience 112: 841-850.

Palmieri, R. M., Ingersoll, C. D. & Hoffman, M. A. 2004. The Hoffmann Reflex: Methodologic Considerations and Applications for Use Sports Medicine and Athletic Training Research. Journal of Athletic Training 39(3): 268-277.

Pascual-Leone, A., Dang, N., Cohen, L. G., Brasil-Neto, J. P., Cammarota, A. & Hallett, M. 1995. Modulation of Muscle Responses Evoked by Transcranial Magnetic Stimulation During the Acquisition of New Fine Motor Skills. Journal of Neurophysiology 74(3): 1037-1045.

Paz, R., Boraud, T., Natan, C., Bergman, H. & Vaadia, E. 2003. Preparatory activity in motor cortex reflects learning of local visuomotor skills. Nature Neuroscience 6(8): 882-890.

Perez, M. A., Lungholt, B. K. S., Nyborg, K. & Nielsen, J. B. 2004. Motor skill training induces changes in the excitability of the leg cortical area in healthy humans. Experimental Brain Research 159: 197-205.

Perez, M. A., Lungholt, B. K. S. & Nielsen, J. B. 2005. Presynaptic control of group Ia afferents in relation to acquisition of a visuo-motor skill in healthy humans. The Journal of Physiology 568(1): 343-354.

Perez, M. A., Lundbye-Jensen, J. & Nielsen, J. B. 2007. Task-Specific Depression of the Soleus H-Reflex After Cocontraction Training of Antagonistic Ankle Muscles. The Journal of Neurophysiology 98: 3677-3687.

Petersen, N. T., Pyndt, H. S. & Nielsen, J. B. 2003. Investigating human motor control by transcranial magnetic stimulation. Experimental Brain Research 152: 1-16.

Plowman, E. K. & Kleim, J. A. 2010. Motor cortex reorganization across the lifespan. Journal of Communication Disorders 43: 286-294.

Quartarone, A., Bagnato, S., Rizzo, V., Morgante, F., Sant'Angelo, A., Battaglia, F., Messina, C., Siebner, H. R. & Girlanda, P. 2004. Distinct changes in cortical and spinal excitability following high-frequency repetitive TMS to the human motor cortex. Experimental Brain Research 161: 114-124.

Randomization.com. 2017. Cited 24th September 2019. http://www.jerrydallal.com/random/permute.htm

Reis, J., Swayne, O. B., Vandermeeren, Y., Camus, M., Dimyan, M. A., Harris-Love, M., Perez, M., Ragert, P., Rothwell, J. C. & Cohen, L. G. 2008. Contribution of transcranial magnetic stimulation to the understanding of cortical mechanisms involved in motor control. Journal of Physiology 586(2): 325-351.

Rosenkranz, K., Williamon, A. & Rothwell, J. C. 2007a. Motorcortical Excitability and Synaptic Plasticity Is Enhanced in Professional Musicians. The Journal of Neuroscience 27: 5200-5206.

Rosenkranz, K., Kacar, A. & Rothwell, J. C. 2007b. Differential Modulation of Motor Cortical Plasticity and Excitability in Early and Late Phases of Human Motor Learning. The Journal of Neuroscience 27(44): 12058-12066.

Rossini, P. M., Burke, D., Chen, R., Cohen, L. G., Daskalakis, Z., Di Iorio, R., Di Lazzaro, V., Ferreri, F., Fitzgerald, P. B., George, M. S., Hallett, M., Lefaucher, J. P., Langguth, B., Matsumoto, H., Miniussi, C., Nitsche, M. A., Pascual-Leone, A., Paulus, W., Rossi, S., Rothwell, J. C., Siebner, H. R., Ugawa, Y., Walsh, V & Ziemann, U. 2015. Non-invasive electric and magnetic stimulation of the brain, spinal cord, roots and peripheral nerves: Basic principles and procedures for routine clinical and research application. An updated report from an I.F.C.N. Committee. Clinical Neurophysiology 126: 1071-1107.

Rothwell, J. C., Day, B. L., Thompson, P. D. & Kujirai, T. 2009. Short latency intracortical inhibition: one of the most popular tools in human motor neurophysiology. Journal of Physiology 587: 11-12.

Sanes, J. N. & Donoghue, J. P. 2000. Plasticity and Primary Motor Cortex. Annual Review of Neuroscience 23: 393-415.

Schieppati, M. 1987. The Hoffmann Reflex: a Means of Assessing Spinal Reflex Excitability and Its Descending Control in Man. Progress in Neurobiology 28(4): 345-376.

Sekiguchi, H., Namazawa, K. & Suzuki, S. 2003. Differences in recruitment properties of the corticospinal pathway between lengthening and shortening contractions in human soleus muscle. Brain Research 977: 169-179.

Sherrington, C. S., 1913. Reflex inhibition as a factor in the coordination of the movements and postures. Quarterly Journal of Experimental Physiology 6(3): 251-310.

Siebner, H. R. & Rothwell, J. 2003. Transcranial magnetic stimulation: new insights into representational cortical plasticity. Experimental Brain Research 148: 1-16.

Singh, A. M., Neva, J. L. & Staines, W. R. 2014. Acute exercise enhances the response to paired associative stimulation-induced plasticity in the primary motor cortex. Experimental Brain Research 232: 3675-3685.

Sivaramakrishnan, A., Tahara-Eckl, L. & Madhavan, S. 2016. Spatial localization and distribution of the TMS-related ’hotspot’ of the tibialis anterior muscle representation in the healthy and post-stroke motor cortex. Neuroscience Letters 627: 30-35.

Smith, A. E., Sale, M. V., Higgins, R. D., Wittert, G. A. & Pitcher, J. B. 2011. Male human motor cortex stimulus-response characteristics are not altered by aging. Journal of Applied Physiology 110: 206-212.

Sobierajewicz, J., Szarkiewicz, S., Przekoracka-Krawczyk, A., Jaśkowski, W. & van der Lubbe, R. 2016. To What Extent Can Motor Imagery Replace Motor Execution While Learning a Fine Motor Skill? Advances in Cognitive Psychology 12(4): 179-192.

Spampinato, D. A., Block, H. J. & Celnik, P. A. 2017. Cerebellar-M1 Connectivity Changes Associated with Motor Learning Are Somatotropic Specific. The Journal of Neuroscience 37(9): 2377-2386.

Stefan, K., Kunesch, E., Cohen, L. G., Benecke, R. & Classen, J. 2000. Induction of plasticity in the human motor cortex by paired associative stimulation. Brain 123: 572-584.

Stefan, K., Wycislo, M. & Classen, J. 2004. Modulation of Associative Human Motor Cortical Plasticity by Attention. Journal of Neurophysiology 92: 66-72.

Stippich, C., Ochmann, H. & Sartor, K. 2002. Somatotopic mapping of the human primary sensorimotor cortex during motor imagery and motor execution by functional magnetic resonance imaging. Neuroscience Letters 331: 50-54.

Swain, R. A., Harris, A. B., Wiener, E. C., Dutka, M. V., Morris, H. D., Theien, B. E., Konda, S., Engberg, K., Lauterbur, P. C. and Greenough, W. T. 2003. Prolonged exercise induces angiogenesis and increases cerebral blood volume in primary motor cortex of the rat. Neuroscience 117: 1037-1046.

Taube, W., Schubert, M., Gruber, M., Beck, S., Faist, M. & Gollhofer, A. 2006. Direct corticospinal pathways contribute to neuromuscular control of perturbed stance. Journal of Applied Physiology 101: 420-429.

Taylor-Clarke, M., Kenett, S. & Haggard, P. 2002. Vision modulates somatosensory cortical processing. Current Biology 12: 233-236.

Van Praag, H., Kempermann, G. & Gage, F. H. 1999. Running increases cell proliferation and neurogenesis in the adult mouse dentate gyrus. Nature Neuroscience 2(3): 266-270.

Veldman, M. P., Zijdewind, I., Solnik, S., Maffiuletti, N. A., Berghuis, K. M. M., Javet, M., Négyesi, J. & Hortobágyi, T. 2015. Direct and crossed effects of somatosensory electrical stimulation on motor learning and neuronal plasticity in humans. European Journal of Applied Physiology 115: 2505-2519.

Visser, J. E. & Bloem, B. R. 2005. Role of the Basal Ganglia in Balance Control. Neural Plasticity 12(2-3): 161-174.

Wagle-Shukla, A., Ni, Z., Gunraj, C. A., Bahl, N. & Chen, R. 2009. Effects of short interval intracortical inhibition and intracortical facilitation on short interval intracortical facilitation in human primary motor cortex. Journal of Physiology 587(23): 5665-5678.

Williams, S. E., Cumming, J., Ntoumanis, N., Nordin-Bates, S. N., Ramsey, R. & Hall, C. 2012. Further validation and development of the Movement Imagery Questionnaire. Journal of Sport & Exercise Physiology 34: 621-646.

Wolpaw, J. R. 2007. Spinal cord plasticity in acquisition and maintenance of motor skills. Acta Physiologica 189: 155-169.

Wulf, G., Shea, C. & Lewthwaite, R. 2010. Motor skill learning and performance: a review of influential factors. Medical Education 44: 75-84.

Yavuz, U. S., Negro, F., Diedrichs, R. & Farina, D. 2018. Reciprocal inhibition between motor neurons of the tibialis anterior and triceps surae in humans. Journal of Neurophysiology 119: 1699-1706.

Ziemann, U., Rothwell, J. C. & Ridding, M. C. 1996. Interaction between intracortical inhibition and facilitation in human motor cortex. Journal of Physiology 496: 873-881.

Ziemann, U. & Siebner, H. R. 2008. Modifying motor learning through gating and homeostatic metaplasticity. Brain Stimulation 1: 60-66.

APPENDICES

Appendix 1 – Subjects' Written Consent

JYVÄSKYLÄN YLIOPISTO

SUOSTUMUS TIETEELLISEEN TUTKIMUKSEEN

Minua on pyydetty osallistumaan tutkimukseen hetkellisen visuaalisen deprivaation vaikutus motoriseen taidon oppimiseen ja kortikaalisen herkkyyteen.
Olen perehtynyt tutkimusta koskevaan tiedotteeseen (tietosuojailmoitus) ja saanut riittävästi tietoa tutkimuksesta ja sen toteuttamisesta. Tutkimuksen sisältö on kerrottu minulle myös suullisesti ja olen saanut riittävän vastauksen kaikkiin tutkimusta koskeviin kysymyksiini. Selvitykset antoivat Anna Nätkynmäki, Joona Juurakko tai Valtteri Huttunen. Minulla on ollut riittävästi aikaa harkita tutkimukseen osallistumista.
Ymmärrän, että tähän tutkimukseen osallistuminen on vapaaehtoista. Minulla on oikeus, milloin tahansa tutkimuksen aikana ja syytä ilmoittamatta keskeyttää tutkimukseen osallistuminen tai peruuttaa suostumukseni tutkimukseen. Tutkimuksen keskeyttämisestä tai suostumuksen peruuttamisesta ei aiheudu minulle kielteisiä seuraamuksia.

En osallistu mittauksiin flunssaisena, kuumeisena, toipilaana tai muuten huonovointisena.

Olen tutustunut tietosuojailmoituksessa kerrottuihin rekisteröidyn oikeusiin ja rajoituksiin.

Allekirjoittamalla suostumuslomakkeen hyväksyn tietojeni käytön tietosuojailmoituksessa kuvattuun tutkimukseen.
☐ Kyllä

Suostun siihen, että tutkimuksessa käsitellään anatomisia, terveydellisiä ja fyysisen aktiivisuuden tietoja.
☐ Kyllä

Suostun siihen, että tutkimuksessa käsitellään erityisiin henkilötietoryhmiin kuuluvia tietoja (terveyttä koskevat tiedot).
☐ Kyllä

Allekirjoituksellani vahvistan, että osallistun tutkimukseen ja suostun vapaaehtoisesti tutkittavaksi sekä annan luvan edellä kerrottuihin asioihin.

___________________________ *Allekirjoitus*	______________________________________ *Päiväys*
____________________________ *Nimen selvennys*	______________________________________ *Syntymäaika*

____

Osoite

Suostumus vastaanotettu

_____________________________________ *Suostumuksen vastaanottajan allekirjoitus*	______________________________________ *Päiväys*

____

Nimen selvennys

Alkuperäinen allekirjoitettu asiakirja jää tutkimuksen vastuullisen johtajan arkistoon ja kopio annetaan tutkittavalle. Suostumusta säilytetään tietoturvallisesti niin kauan kuin aineisto on tunnisteellisessa muodossa. Jos aineisto anonymisoidaan tai hävitetään suostumusta ei tarvitse enää säilyttää.

Appendix 2 – The Subjects Background Information Form

Proprioseptiikan ja näköaistin väliaikaisen poiston vaikutus motorisen taidon oppimiseen ja kortikaaliseen herkkyyteen – tutkimukseen osallistuminen

Vastaathan lomakkeeseen tarkasti ja totuudenmukaisesti.
Koehenkilön esitietolomake, terveyskysely sekä taustatiedot.

Nimi

Sähköposti

Pituus		Paino	
	cm		Kg

Vastaa seuraaviin kysymyksiin

1. ☐ En omaa säännöllistä lääkitystä vaativia sairauksia (esim. astma, diabetes).

Jos omaan, mitä? ____

2. ☐ Minulle ei ole tehty maksimaalista nilkan koukistusliikkeen tuottamista haittaavia leikkauksia.

Jos on, mitä? ____

3. ☐ Minulla ei ole epilepsiaa tai tajuttomuus-/kouristuskohtauksia.
4. ☐ Minulle ei koidu pidemmän ajanjakson istumisesta (n. 1h) vaarallisen alhaista verenpainetta.
5. ☐ Minulla ei ole kehossa sähköisiä tahdistimia.
6. ☐ Minulla ei ole kehossa magneettisia tai metallisia esineitä.

Jos on, mitä? ____

7. ☐ En ole raskaana.

Jos tutkimukseen osallistuva henkilö omaa edellä mainittuja aiheita, tulee hänen ennen osallistumista selventää asia tutkimuksen vastuulliselle tutkijalle, jolloin mahdollinen tutkimukseen osallistuminen arvioidaan uudelleen tutkittavan terveydentilanne huomioiden. Kohdat 3, 4, 5 ja 7 estävät tutkimukseen osallistumisen, mutta kohdat 1,2 ja 6 tulee selvittää tutkimuksen vastuullisen tutkijan.

Liikuntatausta

Urheilulaji(t):

____

Viimeisen neljän (4) tunnin liikunta:

____

____

Muuta mainittavaa:

____

____

Kiitos!

Paikka ja aika Allekirjoitus

/ / 2019

______________________ ______________________

Appendix 3 – Movement Imagery Questionnaire-3 in English

ID:_______________

Movement Imagery Questionnaire-3

Overview:

The MIQ-3 is the most recent version of the Movement Imagery Questionnaire (Hall & Pongrac, 1983) and the Movement Imagery Questionnaire-Revised (Hall & Martin, 1997). It is a 12-item questionnaire to assess individual's ability to image four movements using internal visual imagery, external visual imagery, and kinesthetic imagery. The MIQ-3 has good psychometric properties, internal reliability, and predictive validity.

Reference:

Williams, S. E., Cumming, J., Ntoumanis, N., Nordin-Bates, S. M., Ramsey, R., & Hall, C. (2012). Further validation and development of the Movement Imagery Questionnaire. *Journal of Sport & Exercise Psychology, 34*, 621-646.

To download full paper, please click here:

http://works.bepress.com/jennifer_cumming/27/

*If you decide to use the MIQ-3 in your research, please send any citations to j.cumming@bham.ac.uk. We will add this information to www.jennifercumming.com so that other interested imagery researchers can find your work. We would also appreciate receiving a copy of your research findings.

Movement Imagery Questionnaire-3

Full Questionnaire with Instructions

Instructions

This questionnaire concerns two ways of *mentally* performing movements which are used by some people more than by others, and are more applicable to some types of movements than others. The first is attempting to form a visual image or picture of a movement in your mind. The second is attempting to feel what performing a movement is like without actually doing the movement. You are requested to do both of these mental tasks for a variety of movements in this questionnaire, and then rate how easy/difficult you found the tasks to be. The ratings that you give are not designed to assess the goodness or badness of the way you perform these mental tasks. They are attempts to discover the capacity individuals' show for performing these tasks for different movements. There are no right or wrong ratings or some ratings that are better than others.

Each of the following statements describes a particular action or movement. Read each statement carefully and then actually perform the movement as described. Only perform the movement a single time. Return to the starting position for the movement just as if you were going to perform the action a second time. Then depending on which of the following you are asked to do, either (1) form as clear and vivid a visual image as possible of the movement just performed from an internal perspective (i.e., from a 1st person perspective, as if you are actually inside yourself performing and seeing the action through your own eyes), (2) form as clear and vivid a visual image as possible of the movement just performed from an external perspective (i.e., from a 3rd person perspective, as if watching yourself on DVD), or (3) attempt to feel yourself making the movement just performed without actually doing it.

After you have completed the mental task required, rate the ease/difficulty with which you were able to do the task. Take your rating from the following scale. Be as accurate as possible and take as long as you feel necessary to arrive at the proper rating for each movement. You may choose the same rating for any number of movements "seen" or "felt" and it is not necessary to utilize the entire length of the scale.

RATING SCALES

Visual Imagery Scale

1	2	3	4	5	6	7
Very hard to see	Hard to see	Somewhat hard to see	Neutral (not easy nor hard)	Somewhat easy to see	easy to see	Very easy to see

Kinesthetic Imagery Scale

1	2	3	4	5	6	7
Very hard to feel	Hard to feel	Somewhat hard to feel	Neutral (not easy nor hard)	Somewhat easy to feel	easy to feel	Very easy to feel

1. STARTING POSITION: Stand with your feet and legs together and your arms at your sides.

ACTION: Raise your right knee as high as possible so that you are starting on your left leg with your right leg flexed (bent) at the knee. Now lower your right leg so you are once again standing on two feet. The action is performed **slowly**.

MENTAL TASK: Assume the starting position. Attempt to **feel** yourself making the movement just observed without actually doing it. Now rate the ease/difficulty with which you were able to do this mental task.

Rating: __________

2. STARTING POSITION: Stand with your feet and legs together and your arms at your sides.

ACTION: Bend down low and then jump straight up in the air as high as possible with both arms extended above your head. Land with both feet apart and lower your arms to your sides.

MENTAL TASK: Assume the starting position. Attempt to **see** yourself making the movement just observed from an **internal perspective**. Now rate the ease/difficulty with which you were able to do this mental task.

Rating: __________

.

3. STARTING POSITION: Extend the arm of your non-dominant hand straight out to your side so that it is parallel to the ground, palm down.

ACTION: Move your arm forward until it is directly in front of your body (still parallel to the ground). Keep your arm extended during the movement, and make the movement **slowly**.

MENTAL TASK: Assume the starting position. Attempt to **see** yourself making the movement just observed from an **external perspective**. Now rate the ease/difficulty with which you were able to do this mental task and the angle the image was observed from (see additional sheet provided for full list of different angles)

Rating: __________

4. STARTING POSITION: Stand with your feet slightly apart and your arms fully extended above your head.

ACTION: **Slowly** bend forward at the waist and try and touch your toes with your fingertips (or, if possible, touch the floor with your fingertips or your hands). Now return to the starting position, standing erect with your arms extended above your head.

MENTAL TASK: Assume the starting position. Attempt to **feel** yourself making the movement just observed without actually doing it. Now rate the ease/difficulty with which you were able to do this mental task.

Rating: __________

5. STARTING POSITION: Stand with your feet and legs together and your arms at your sides.

ACTION: Raise your right knee as high as possible so that you are starting on your left leg with your right leg flexed (bent) at the knee. Now lower your right leg so you are once again standing on two feet. The action is performed **slowly**.

MENTAL TASK: Assume the starting position. Attempt to **see** yourself making the movement just observed from an **internal perspective**. Now rate the ease/difficulty with which you were able to do this mental task.

Rating: __________

6. STARTING POSITION: Stand with your feet and legs together and your arms at your sides.

ACTION: Bend down low and then jump straight up in the air as high as possible with both arms extended above your head. Land with both feet apart and lower your arms to your sides.

MENTAL TASK: Assume the starting position. Attempt to **see** yourself making the movement just observed from **an external perspective**. Now rate the ease/difficulty with which you were able to do this mental task and the angle the image was observed from (see additional sheet provided for full list of different angles)

Rating: __________

7. STARTING POSITION: Extend the arm of your non-dominant hand straight out to your side so that it is parallel to the ground, palm down.

ACTION: Move your arm forward until it is directly in front of your body (still parallel to the ground). Keep your arm extended during the movement, and make the movement **slowly**.

MENTAL TASK: Assume the starting position. Attempt to **feel** yourself making the movement just performed without actually doing it. Now rate the ease/difficulty with which you were able to do this mental task.

Rating: __________

8. STARTING POSITION: Stand with your feet slightly apart and your arms fully extended above your head.

ACTION:: **Slowly** bend forward at the waist and try and touch your toes with your fingertips (or, if possible, touch the floor with your fingertips or your hands). Now return to the starting position, standing erect with your arms extended above your head.

MENTAL TASK: Assume the starting position. Attempt to **see** yourself making the movement just observed from an **internal perspective**. Now rate the ease/difficulty with which you were able to do this mental task.

Rating: __________

9. STARTING POSITION: Stand with your feet and legs together and your arms at your sides.

ACTION: Raise your right knee as high as possible so that you are starting on your left leg with your right leg flexed (bent) at the knee. Now lower your right leg so you are once again standing on two feet. The action is performed **slowly**.

MENTAL TASK: Assume the starting position. Attempt to **see** yourself making the movement just observed from **an external perspective**. Now rate the ease/difficulty with which you were able to do this mental task and the angle the image was observed from (see additional sheet provided for full list of different angles)

Rating: __________

10. STARTING POSITION: Stand with your feet and legs together and your arms at your sides.

ACTION: Bend down low and then jump straight up in the air as high as possible with both arms extended above your head. Land with both feet apart and lower your arms to your sides.

MENTAL TASK: Assume the starting position. Attempt to **feel** yourself making the movement just performed without actually doing it. Now rate the ease/difficulty with which you were able to do this mental task.

Rating: __________

11. STARTING POSITION: Extend the arm of your non-dominant hand straight out to your side so that it is parallel to the ground, palm down.

ACTION: Move your arm forward until it is directly in front of your body (still parallel to the ground). Keep your arm extended during the movement, and make the movement **slowly**.

MENTAL TASK: Assume the starting position. Attempt to **see** yourself making the movement just observed from an **internal perspective**. Now rate the ease/difficulty with which you were able to do this mental task.

Rating: __________

12. STARTING POSITION: Stand with your feet slightly apart and your arms fully extended above your head.

ACTION: **Slowly** bend forward at the waist and try and touch your toes with your fingertips (or, if possible, touch the floor with your fingertips or your hands). Now return to the starting position, standing erect with your arms extended above your head.

MENTAL TASK: Assume the starting position. Attempt to **see** yourself making the movement just observed from an **external perspective**. Now rate the ease/difficulty with which you were able to do this mental task and the angle the image was observed from (see additional sheet provided for full list of different angles)

Rating: __________

Movement Imagery Questionnaire-3

Response Form Only
(if Instructions and Items are read to participants)

After you have completed the mental task required, rate the ease/difficulty with which you were able to do the task in the space provided below. Take your rating from the provided scale. Be as accurate as possible and take as long as you feel necessary to arrive at the proper rating for each movement. You may choose the same rating for any number of movements "seen" or "felt" and it is not necessary to utilise the entire length of the scale.

RATING SCALES

Visual Imagery Scale

1	2	3	4	5	6	7
Very hard to see	Hard to see	Somewhat hard to see	Neutral (not easy nor hard)	Somewhat easy to see	easy to see	Very easy to see

Kinesthetic Imagery Scale

1	2	3	4	5	6	7
Very hard to feel	Hard to feel	Somewhat hard to feel	Neutral (not easy nor hard)	Somewhat easy to feel	easy to feel	Very easy to feel

1) Knee lift Rating: ____

2) Jump Rating : ____

3) Arm movement Rating:____

4) Waist Bend Rating: ____

5) Knee lift Rating: ____

6) Jump Rating:____

7) Arm movement Rating: ____

8) Waist Bend Rating: ____

9) Knee lift Rating:____

10) Jump Rating: ____

11) Arm movement Rating: ____

12) Waist Bend Rating:____

Movement Imagery Questionnaire-3

Instructions for Scoring

Subscale	Items
Internal Visual Imagery	Item 2 + Item 5 + Item 8 + Item 11/4
External Visual Imagery	Item 3 + Item 6 + Item 9 + Item 12/4
Kinesthetic Imagery	Item 1 + Item 4 + Item 7 + Item 10/4

Appendix 4 – Movement Imagery Questionnaire-3 translated to Finnish

ID:_______________

Movement Imagery Questionnaire-3

LIIKKEEN MIELIKUVITTELUN TEHTÄVÄKYSELY (MIQ-3) - SUOMENNOS

Overview:

The MIQ-3 is the most recent version of the Movement Imagery Questionnaire (Hall & Pongrac, 1983) and the Movement Imagery Questionnaire-Revised (Hall & Martin, 1997). It is a 12-item questionnaire to assess individual's ability to image four movements using internal visual imagery, external visual imagery, and kinesthetic imagery. The MIQ-3 has good psychometric properties, internal reliability, and predictive validity.

Yleiskatsaus:

MIQ-3 on uusin versio Hall & Pongrac:n (1983) tekemästä "Movement Imagery Questionnaire" -tehtäväkyselystä, jota on myös aikaisemmin päivitetty Hall & Martinin (1997) toimesta (Movement Imagery Questionnaire-Revised). MIQ-3 tehtävkyselyssä on 12 – tehtävää, joiden avulla pyritään kartoittamaan yksilön mielikuvittelukyvykkyys kolmessa eri kategoriassa; sisäinen visuaalinen mielikuvittelu, ulkoinen visuaalinen mielikuvittelu ja kinesteettinen mielikuvittelu. MIQ-3 omaa hyvät psykometriset ominaisuudet, sisäisen reliabiliteetin ja ennustevaliditeetin.

Lähteet:

Williams, S. E., Cumming, J., Ntoumanis, N., Nordin-Bates, S. M., Ramsey, R., & Hall, C. (2012). Further validation and development of the Movement Imagery Questionnaire. Journal of Sport & Exercise Psychology, 34, 621-646.

Kokonaisartikkelin saat seuraavasta linkistä:

http://works.bepress.com/jennifer_cumming/27/

*If you decide to use the MIQ-3 in your research, please send any citations to j.cumming@bham.ac.uk. We will add this information to www.jennifercumming.com so that other interested imagery researchers can find your work. We would also appreciate receiving a copy of your research findings.

Suomennoksen toteuttanut:

Joona Juurakko, joemoiju@student.jyu.fi, LitK opiskelija, 23.11.2018.

Movement Imagery Questionnaire-3

LIIKKEEN MIELIKUVITTELUN TEHTÄVÄKYSELY (MIQ-3)

TÄYDELLINEN TEHTÄVÄKYSELY OHJEISTUKSELLA

Ohjeistus

Tämä kyselytehtävä sisältää kaksi tapaa, joilla voidaan mielikuvitella liikettä. Toinen tapa sopii hieman paremmin toisen tyyppisen liikkeen kuvitteluun ja toinen toisen tyyppiseen. Jotkut ihmiset käyttävät toista tapaa mielikuvitella enemmän kuin toista. Ensimmäinen tapa pyrkii muodostamaan liikkeestä visuaalisen kuvauksen, kuvan tai esimerkiksi videon tyyppisen esityksen mieleesi. Toisessa tavassa pyritään tuntemaan kehossa, miltä liike tuntuisi ilman, että sitä oikeasti toteutetaan. Tässä kyselytehtävässä tulet suorittamaan molempia mielikuvittelun muotoja erilaisista liikkeistä, jonka jälkeen sinua pyydetään arvioimaan kuinka helppona tai haastavana liikkeen mielikuvittelun koit. Antamasi arvion tarkoitus ei ole määrittää kuinka hyvin tai huonosti selviydyit mielikuvittelutehtävästä. Arvioinnin perusteella pyritään selvittämään yksilön kapasiteettia suorittaa mielikuvitustehtävät erilaisille liikkeille. Tässä tehtäväkyselyssä ei ole oikeaa tai väärää arviota. Myöskään toiset arviot eivät ole toisia arvioita parempia.

Jokainen seuraavista tehtävistä kuvaa tiettyä toimintaa tai liikettä. Lue jokainen tehtävä ensin huolella, jonka jälkeen suoritat liike tehtävän kuvailemalla tavalla. Suorita tehtävän liike vain yhden kerran. Suorituksen jälkeen palaa alkuasentoon, aivan kuin olisit suorittamassa liikettä toistamiseen. Tämän jälkeen suoritetaan tehtävän mukainen mielikuvaharjoite, joka on jokin seuraavista: (1) Muodosta sisäisen perspektiivin näkökulmasta mahdollisimman selvä ja yksiselitteinen mielikuva äskettäin toteuttamastasi liikkeestä. (Sisäinen perspektiivi = 1. persoonan perspektiivistä nähtävä eli kuvittelet olevasi itsesi sisällä ja näkisit omien silmiesi kautta liikkeen toteutuksen.) (2) Muodosta ulkoisen perspektiivin näkökulmasta mahdollisimman selvä ja yksiselitteinen mielikuva äskettäin toteuttamastasi liikkeestä (Ulkoinen perspektiivi = 3. persoonan perspektiivistä nähtävä eli kuvittelet liikkeen kuin katselisit itseäsi videolta.) (3) Yritä tuntea itsesi tekemässä liikettä ilman, että oikeasti teet liikettä.

Tehtyäsi tehtävässä vaaditun mielikuvitteluosuuden, arvioi suoritetun mielikuvittelun haastavuus/helppous. Alapuolella esitellään arviointi skaala. Ole mahdollisimman tarkka arviossasi ja käytä niin paljon aikaa kuin tarvitset pohtiessasi oikeaa arviota jokaisen tehtävän kohdalla. Voit valita saman arvion, mille tahansa liikkeelle eikä kaikkia arviointi skaalan tuloksia ole pakko käyttää.

ARVIOINTI SKAALA

Visuaalisen Mielikuvittelun Skaala

1	2	3	4	5	6	7
Erittäin Vaikea Nähdä	Vaikea Nähdä	Melko Vaikeaa Nähdä	Neutraali (ei helppoa eikä vaikeaa)	Melko Helppoa Nähdä	Helppo Nähdä	Todella Helppo Nähdä

Kinesteettisen Mielikuvittelun Skaala

1	2	3	4	5	6	7
Erittäin Vaikea Tuntea	Vaikea Tuntea	Melko Vaikeaa Tuntea	Neutraali (ei helppoa eikä vaikeaa)	Melko Helppoa Tuntea	Helppoa Tuntea	Todella Helppoa Tuntea

1. ALOITUSASENTO: Seiso jalat yhdessä ja kädet vartalosi vierellä.

TOIMINTA: Nosta oikea polvesi niin korkealle kuin mahdollista, siten että käyt seisomaan vasemmalle jalalle samalla oikea raaja on koukistunut polven kohdalta. Nyt laske oikea jalkasi ja seisot taas kahdella jalalla. Toiminta kuuluu tehdä **hitaasti.**

MIELIKUVITTELUTEHTÄVÄ: Ota tehtävän aloitusasento. Yritä **tuntea** itsesi tekemässä äskettäin suorittamasi liike siten, ettet oikeasti toteuta sitä. Nyt arvioi kuinka helppoa/haastavaa mielikuvittelutehtävän tekeminen sinulle oli.

Arvio: __________

2. ALOITUSASENTO: Seiso jalat yhdessä ja kädet vartalosi vierellä.

TOIMINTA: Kyykisty ja hyppää suoraan ilmaan niin korkealle kuin pystyt siten, että suoristat hypyn aikana molemmat kätesi pääsi yläpuolelle. Tee alastulo jalat hieman haarallaan ja laske kätesi vartalon vierelle.

MIELIKUVITTELUTEHTÄVÄ: Ota tehtävän aloitusasento. Yritä **nähdä** itsesi suorittamassa äskettäin suorittamasi liike **sisäisestä perspektiivistä**. Nyt arvioi kuinka helppoa/haastavaa mielikuvittelutehtävän tekeminen sinulle oli.

Arvio: __________

.

3. ALOITUSASENTO: Seiso ei hallitsevan kätesi käsivarsi ojennettuna suoraksi sivulle päin siten, että käsivartesi on lattian kanssa samansuuntaisesti, kämmen kohti lattiaa.

TOIMINTA: Liikuta kätesi osoittamaan suoraan eteenpäin (käsivarsi edelleen lattian kanssa samansuuntaisesti). Pidä käsivartesi ojennettuna koko liikkeen ajan. Liike tulee tehdä **hitaasti**.

MIELIKUVITTELUTEHTÄVÄ: Ota tehtävän aloitusasento. Yritä **nähdä** itsesi suorittamassa äskettäin suorittamasi liike **ulkoisesta perspektiivistä.** Nyt arvioi kuinka helppoa/haastavaa mielikuvittelutehtävän tekeminen sinulle oli ja kirjaa mistä kulmasta katselit itseäsi.

Arvio: __________

Katselukulma: ______________

4. ALOITUSASENTO: Seiso jalat hieman haarallaan ja molemmat kädet pään yläpuolelle ojennettuina.

TOIMINTA: Kurota **hitaasti** kohti varpaita lantiosta taivuttaen. Yritä koskettaa varpaitasi sormenpäilläsi (tai, jos mahdollista, kosketa lattiaa sormenpäilläsi tai käsilläsi). Nyt palaa aloitusasentoon, seiso suorassa kädet ojennettuina pääsi yläpuolelle.

MIELIKUVITTELUTEHTÄVÄ: Ota tehtävän aloitusasento. Yritä **tuntea** itsesi tekemässä äskettäin suorittamasi liike siten, ettet oikeasti toteuta sitä. Nyt arvioi kuinka helppoa/haastavaa mielikuvittelutehtävän tekeminen sinulle oli.

Arvio: __________

5. ALOITUSASENTO: Seiso jalat yhdessä ja kädet vartalosi vierellä.

TOIMINTA: Nosta oikea polvesi niin korkealle kuin mahdollista, siten että käyt seisomaan vasemmalle jalalle samalla oikea raaja on koukistunut polven kohdalta. Nyt laske oikea jalkasi ja seisot taas kahdella jalalla. Toiminta kuuluu tehdä **hitaasti.**

MIELIKUVITTELUTEHTÄVÄ: Ota tehtävän aloitusasento. Yritä **nähdä** itsesi suorittamassa äskettäin suorittamasi liike **sisäisestä perspektiivistä**. Nyt arvioi kuinka helppoa/haastavaa mielikuvittelutehtävän tekeminen sinulle oli.

Arvio: __________

6. ALOITUSASENTO: Seiso jalat yhdessä ja kädet vartalosi vierellä.

TOIMINTA: Kyykisty ja hyppää suoraan ilmaan niin korkealle kuin pystyt siten, että suoristat hypyn aikana molemmat kätesi pääsi yläpuolelle. Tee alastulo jalat hieman haarallaan ja laske kätesi vartalon vierelle.

MIELIKUVITTELUTEHTÄVÄ: Ota tehtävän aloitusasento. Yritä **nähdä** itsesi suorittamassa äskettäin suorittamasi liike **ulkoisesta perspektiivistä.** Nyt arvioi kuinka helppoa/haastavaa mielikuvittelutehtävän tekeminen sinulle oli ja kirjaa mistä kulmasta katselit itseäsi.

Arvio: __________

Katselukulma: ___________________

7.	ALOITUSASENTO:	Seiso ei hallitsevan kätesi käsivarsi ojennettuna suoraksi sivulle päin siten, että käsivartesi on lattian kanssa samansuuntaisesti, kämmen kohti lattiaa.
	TOIMINTA:	Liikuta kätesi osoittamaan suoraan eteenpäin (käsivarsi edelleen lattian kanssa samansuuntaisesti). Pidä käsivartesi ojennettuna koko liikkeen ajan. Liike tulee tehdä **hitaasti**.
	MIELIKUVITTELUTEHTÄVÄ:	Ota tehtävän aloitusasento. Yritä **tuntea** itsesi tekemässä äskettäin suorittamasi liike siten, ettet oikeasti toteuta sitä. Nyt arvioi kuinka helppoa/haastavaa mielikuvittelutehtävän tekeminen sinulle oli.

Arvio: __________

8.	ALOITUSASENTO:	Seiso jalat hieman haarallaan ja molemmat kädet pään yläpuolelle ojennettuina.
	TOIMINTA:	Kurota **hitaasti** kohti varpaita lantiosta taivuttaen. Yritä koskettaa varpaitasi sormenpäilläsi (tai, jos mahdollista, kosketa lattiaa sormenpäilläsi tai käsilläsi). Nyt palaa aloitusasentoon, seiso suorassa kädet ojennettuina pääsi yläpuolelle.
	MIELIKUVITTELUTEHTÄVÄ:	Ota tehtävän aloitusasento. Yritä **nähdä** itsesi suorittamassa äskettäin suorittamasi liike **sisäisestä perspektiivistä**. Nyt arvioi kuinka helppoa/haastavaa mielikuvittelutehtävän tekeminen sinulle oli.

Arvio: __________

9.	ALOITUSASENTO:	Seiso jalat yhdessä ja kädet vartalosi vierellä.
	TOIMINTA:	Nosta oikea polvesi niin korkealle kuin mahdollista, siten että käyt seisomaan vasemmalle jalalle samalla oikea raaja on koukistunut polven kohdalta. Nyt laske oikea jalkasi ja seisot taas kahdella jalalla. Toiminta kuuluu tehdä **hitaasti.**
	MIELIKUVITTELUTEHTÄVÄ:	Ota tehtävän aloitusasento. Yritä **nähdä** itsesi suorittamassa äskettäin suorittamasi liike **ulkoisesta perspektiivistä.** Nyt arvioi kuinka helppoa/haastavaa mielikuvittelutehtävän tekeminen sinulle oli ja kirjaa mistä kulmasta katselit itseäsi.

Arvio: __________

Katselukulma: __________________

10.	ALOITUSASENTO:	Seiso jalat yhdessä ja kädet vartalosi vierellä.
	TOIMINTA:	Kyykisty ja hyppää suoraan ilmaan niin korkealle kuin pystyt siten, että suoristat hypyn aikana molemmat kätesi pääsi yläpuolelle. Tee alastulo jalat hieman haarallaan ja laske kätesi vartalon vierelle.
	MIELIKUVITTELUTEHTÄVÄ:	Ota aloitusasento. Yritä **tuntea** itsesi tekemässä äskettäin suorittamasi liike siten, ettet oikeasti toteuta sitä. Nyt arvioi kuinka helppoa/haastavaa mielikuvittelutehtävän tekeminen sinulle oli.
	Arvio: __________	
11.	ALOITUSASENTO:	Seiso ei hallitsevan kätesi käsivarsi ojennettuna suoraksi sivulle päin siten, että käsivartesi on lattian kanssa samansuuntaisesti, kämmen kohti lattiaa.
	TOIMINTA:	Liikuta kätesi osoittamaan suoraan eteenpäin (käsivarsi edelleen lattian kanssa samansuuntaisesti). Pidä käsivartesi ojennettuna koko liikkeen ajan. Liike tulee tehdä **hitaasti**.
	MIELIKUVITTELUTEHTÄVÄ:	Ota tehtävän aloitusasento. Yritä **nähdä** itsesi suorittamassa äskettäin suorittamasi liike **sisäisestä perspektiivistä**. Nyt arvioi kuinka helppoa/haastavaa mielikuvittelutehtävän tekeminen sinulle oli.
	Arvio: __________	
12.	ALOITUSASENTO:	Seiso jalat hieman haarallaan ja molemmat kädet pään yläpuolelle ojennettuina.
	TOIMINTA:	Kurota **hitaasti** kohti varpaita lantiosta taivuttaen. Yritä koskettaa varpaitasi sormenpäilläsi (tai, jos mahdollista, kosketa lattiaa sormenpäilläsi tai käsilläsi). Nyt palaa aloitusasentoon, seiso suorassa kädet ojennettuina pääsi yläpuolelle.
	MIELIKUVITTELUTEHTÄVÄ:	Ota tehtävän aloitusasento. Yritä **nähdä** itsesi suorittamassa äskettäin suorittamasi liike **ulkoisesta perspektiivistä.** Nyt arvioi kuinka helppoa/haastavaa mielikuvittelutehtävän tekeminen sinulle oli ja kirjaa mistä kulmasta katselit itseäsi.
	Arvio: __________	
	Katselukulma: ______________	

Movement Imagery Questionnaire-3

Vain vastaukset
(Jos ohjeet ja tehtävät luetaan tutkijan toimesta)

Vaaditun mielikuvittelutehtävän jälkeen, arvioi mielikuvittelun helppous/haastavuus alapuolella olevaan lomakkeeseen. Käytä arviossasi alla olevaa skaalausta. Ole mahdollisimman tarkka arviossasi ja käytä niin paljon aikaa kuin tarvitset pohtiessasi oikeaa arviota jokaisen tehtävän kohdalla. Voit valita saman arvion, mille tahansa liikkeelle eikä kaikkia arviointi skaalan tuloksia ole pakko käyttää.

ARVIOINTI SKAALAUS

Visuaalisen Mielikuvittelun Skaala

1	2	3	4	5	6	7
Erittäin Vaikea Nähdä	Vaikea Nähdä	Melko Vaikeaa Nähdä	Neutraali (ei helppoa eikä vaikeaa)	Melko Helppoa Nähdä	Helppo Nähdä	Todella Helppo Nähdä

Kinesteettisen Mielikuvittelun Skaala

1	2	3	4	5	6	7
Erittäin Vaikea Tuntea	Vaikea Tuntea	Melko Vaikeaa Tuntea	Neutraali (ei helppoa eikä vaikeaa)	Melko Helppoa Tuntea	Helppoa Tuntea	Todella Helppoa Tuntea

1) Polven nosto	Arvio: ____	7) Käden like	Arvio: ____
2) Hyppy	Arvio: ____	8) Lantion taivutus	Arvio: ____
3) Käden liike	Arvio:____	9) Polven nosto	Arvio:____
4) Lantion taivutus	Arvio: ____	10) Hyppy	Arvio: ____
5) Polven nosto	Arvio: ____	11) Käden liike	Arvio: ____
6) Hyppy	Arvio:____	12) Lantion taivutus	Arvio:____

Movement Imagery Questionnaire-3

Ohjeistus pisteiden laskuun

Arvioitava alue	**Tehtävät**
Sisäinen Visuaalinen Mielikuvittelu	(Tehtävä 2 + Tehtävä 5 + Tehtävä 8 + Tehtävä 11)/4
Ulkoinen Visuaalinen Mielikuvittelu	(Tehtävä 3 + Tehtävä 6 + Tehtävä 9 + Tehtävä 12)/4
Kinesteettinen mielikuvittelu	(Tehtävä 1 + Tehtävä 4 + Tehtävä 7 + Tehtävä 10)/4

MIQ-3 pisteet:

sVM: ____________

uVM: ____________

KM: _____________