Effects Of Motor Imagery On Upper Extremity Function In Subjects With Cervical Spinal Cord Injury- A Randomized Clinical Trial.

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Abstract: Background and Objectives: Spinal Cord Injury (SCI) is one of the most devastating neurological disorders which involve damage to the central nervous system (CNS). It is followed by structural and functional reorganization and result in recovery of sensory- motor functions. This process can be enhanced through exposing the CNS to one of the technique of motor imagery (MI) with Mental practice. MI has been studied for various neurological disorders including SCI but due to lack in the proper guideline and procedure the research available for SCI is inconclusive with mixed therapeutic benefits. So, this clinical trial was conducted with the aim to develop a structured protocol and to find out the effects on hand function and manual dexterity of incomplete SCI subjects. Materials and methods: Forty Cervical SCI (C-SCI) subjects within 6 month of duration were assigned to the MI group (n = 20) or the conventional group (n = 20). Both group received the same conventional rehabilitation programs and additionally respective intervention i.e. MI group received MI with physical practice (PP) and conventional group received usual upper extremity exercises for 30 minutes per session, 5 days a week for 3 weeks. The Box and Block test (BBT), Action reach arm test (ARAT), Jabsen hand function test (JHFT) and Nine hole peg test (NHPT) were used as an outcome measure to assess gross manual dexterity, motor recovery of upper extremity and hand function at pre and post intervention. Result: At baseline subjects of both group showed no significant differences regarding BBT, ARAT, JHFT and NHPT scores but after 3 weeks of intervention, subjects of both group showed statistically significant improvements in all the variables measured ($p<0{\cdot}05$). Moreover subjects of the MI with PP group had greater improvement in the BBT, ARAT values compared to CT group. Conclusion: The present study confirms that structured protocol used for MI with PP is an effective treatment technique to improve upper extremity motor recovery and hand function in C-SCI subjects compare to CT. It is cost effective, easy and safe method for rehabilitation and most important can be easily administered at home by the subjects. [Rai P Natl J Integr Res Med, 2019; 10(4):18-25]

Key Words: Motor Imagery, Mental practice, Rehabilitation, Spinal cord injury, Upper extremity

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Introduction: Spinal cord injury (SCI) is defined as a lesion within the spinal cord that results in the disruption of nerve fibre bundles that convey ascending sensory and descending motor information[1]. According to WHO fact sheet 2013, every year, around the world, between 2,50,000 and 5,00,000 people sustain SCI [2]. The extent of the damage to the spinal cord is highly variable depending on the level, location and size of insult to the spinal cord. In general the higher up the spinal cord lesion the more extreme the range of impairments will be. The two primary lesions after sustaining a SCI are complete or partial loss (incomplete) of sensory and or motor function below the level of injury[3].

Movement is planned and coordinated by the brain and carried out by contracting muscles acting on specific joints. Motor commands initiated in the brain travel through descending pathways in the spinal cord to effector motor neurons before reaching target muscles[4] . The key pathway necessary for signal transmission between the brain and the rest of the body are disrupted, resulting in paralysis below the injury level[5]. Although SCI interrupts connections between the brain and effector muscles, key planning, co-ordination and effector centres above and below the injury remain intact[6].

A SCI at the cervical level (C-SCI) results in tetraplegia, the loss of hand and upper limb function with impairment or loss of motor and/or sensory function leaving a person highly dependent on their caregiver for most basic activities of daily living (ADLs)[7]. Regardless of injury mechanism, SCI also causes permanent autonomic deficits[8]. The loss of upper limb function, especially the use of the hands is one of the most significant and devastating losses an individual can experience after C-SCI. The use of the upper extremities is critical in completing basic ADLs such as self-feeding, dressing, bathing and toileting. Mobility needs such as transfers from surface to surface, transitional movements such as rolling, bridging and sit to lying down, crutch walking and wheeled mobility is also completed using their arms[8]. So the recovery of hand function is an important meaningful goal among those people[9].Though, the elbow flexors and wrist extensors are spared in C6-C7 level SCI, the ability to move the fingers are disturbed thereby preventing active grasp[10]. Impaired motor and sensory functions in arms and hands result in a loss of joint mobility, grip strength, co-ordination of motion, proprioception and protective sensitivity. In addition, motor spasm may also occur[11].

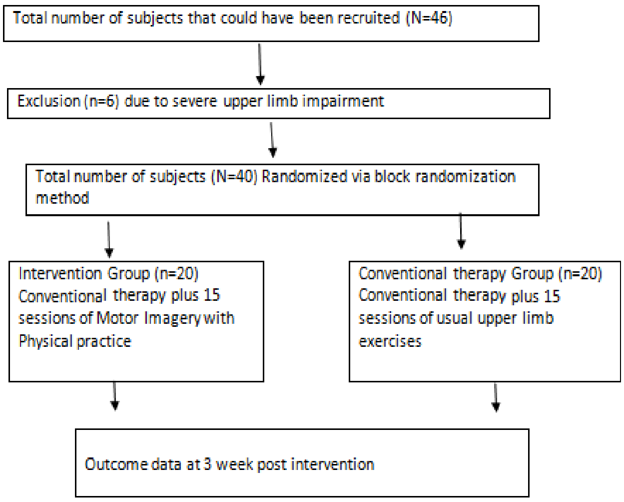
Humans have the ability to generate mental correlates of perceptual and motor events without any triggering external stimulus, a function known as imagery[12]. Motor Imagery (MI) is the imagining of an action without its actual execution. It is a process during which the representation of an action is internally reproduced within the working memory without any overt output[13]. One of the most remarkable features of MI is that it shares common neuronal networks with actual execution[14]. Imagery has been categorized as external (visual) and internal (kinesthetic)[15]. Neuroimaging work by Guillot et al. has demonstrated that the visual imagery activates the visual cortical pathways, whilst kinesthetic imagery predominantly involves the motor associated regions and inferior parietal lobe. Previous research suggests that visualization imagery is easier to perform, but kinesthetic imagery may be more closely allied to actual movement process[16] .

In 1996, Jean Decty suggested that imagined and executed movements were found to activate similar regions of the premotor cortex, basal ganglia and cerebellum that are associated with movement planning, execution and modulation. In 1999 Jeannerod and Frak provided further evidence that the prefrontal cortex, pre-supplementary motor area (preSMA) and the parietal cortex might be involved in MI[17]. At the beginning of the 21st century, attempts were made to transfer the concept of MI from sports psychology to stroke rehabilitation[18]. Page et al and Liu et al tried to combine occupational therapy and MI to improve motor recovery in stroke or brain injury subjects[19]. Besides numerous post-stroke studies, the integration of MI in SCI rehabilitation received limited attention. Numerous neuroimaging studies demonstrated that mental representation is retained in individuals with SCI[20]. Cramer et al identified the activation of similar areas that are involved in the learning process, both in healthy controls and SCI subjects, during MI training of lower limb movements. They suggested that the neural networks controlling movement might be centrally activated above and below the lesion level, even in the absence of peripheral feedback[21]. Aikat and Dua in a systematic review suggested that guidelines are required to be developed to address the issue of a structured procedure to conduct MI in SCI subjects. They emphasized on optimization of training strategies and to develop selective therapies for mental practice for SCI[22]. MI has been studied for SCI for functional recovery but research and literature available is inconclusive with mixed therapeutic benefits. However the best methods of practice of MI in SCI and the details of the techniques used with proper protocol is not available. Despite these findings, the integration of MI in SCI rehabilitation programs for improving hand function and recovery has not yet been experimentally addressed. So the aim of this study was to investigate the effects of MI training in the restoration of motor recovery of upper extremity and hand function in C-SCI subjects.

Method : Study population :C-SCI subjects were recruited from Central Referral Hospital in Sikkim, India. Institutional ethics committee approved the study. Subjects were included in the study if they had (1) C-SCI (C5-C7) diagnosed by a physician, (2) 2 months-6 months post C-SCI, (3)Traumatic and non traumatic C-SCI, (4) Both gender of 20-60 years, (5) AIS (ASIA impairment scale) grades of B and C, (6) Mini-Mental State Examination score (MMSE) ≥ to 24 (21 for illiterate). We also applied the following exclusion criteria: Subjects with any other type of injury that could limit upper extremity function, unable to sit less than 30 minute with support and visual or hearing impairment.

Recruitment and randomization: We used a randomized clinical design in which the subjects were randomized via block randomization method into two groups. The assessor was blinded to the group allocation of each subject. All assessments were performed by the same investigator who was blinded to the treatment assignment. The baseline data regarding name, age, sex, hospital number, hand dominance, post C-SCI duration, type of injury traumatic/non traumatic, the ASIA neurological level , AIS grades of B and C and MMSE was taken after informed consent for all subjects. There was total number of 20 subjects in each group. Since only 3 weeks of intervention and no follow up so no drop out during the study (Fig. 1).

Figure 1: Flow diagram for randomized subject assignment in this study



Intervention and conventional therapy group: The intervention group subjects received MI with physical practice (PP) and additionally regular therapy. It was applied with subjects seating reclined or sitting on a wheelchair in front of a table with the eyes closed. The subjects were familiarized with all tasks during the first session. The therapist showed the movement before the subjects mentally or physically performed it. The subjects were also educated to basic imagery principles and the importance of regular imagery training in increasing therapy success. In total 30 minutes/session MI was given with PP for 5 days /week for 3 consecutive weeks in a quiet room in the department of physiotherapy.

Out of 30 min, initial 5 min was given as relaxation exercise to relax body and mind then 15 min MI for ADLs task performed with the dominant extremity. During MI instruction of imagery exercises were detailed and oriented towards visual and kinesthetic aspects of the task. Next 2 min was allowed to the subjects to refocus into the room. Last 8 min was given for the PP for the same task with open eyes. Visual and kinesthetic imagery was given during training. MI for easiest task was given in the first week with gradually increasing difficulty, whereas the most difficult task was practiced in last week and each session consists of 5 ADLs task given for 30 min (Table 1).

For all tasks a training DVDs was guided to the subjects on weekly basis. The correct task performance was shown on screen combined with verbal explanation. For each task five repetitions was given. DVDs were available for every task for right- and left-handers.

Conventional therapy group :The subjects in conventional therapy group received upper limb Bi manual practice exercises along with regular therapy for thirty minutes per session, five days a week for three weeks. The conventional therapy was subjects-specific and consists of Neurodevelopmental facilitation techniques, Physiotherapy technique and occupational therapy (if needed).

Table 1: Exercise protocol for Motor imagery with Physical practice

1st week	**2nd week**	**3rd week**
1. Making fist & open.	1. Picking pen from table.	1. Write few letter /diagram
2. Holding a pen.	2. Hold cube between two finger and transfer to other hand.	2. Drink water from cup.
3. Holding & rolling cube in hand.	3. Holding cup and placing back.	3. Eat biscuit from table.
4. Reaching toward a cup.	4.Touch mouth and reversing back	4. Turn key/switch/tap.
5. Reaching toward mouth.	5. Fold paper/ towel turn once.	5. Button/unbutton cloth.

Outcome measures: To measure improvement in gross manual dexterity of upper extremity the Box and Block test (BBT)[23], motor recovery of upper extremity the Action reach arm test (ARAT)[24], for hand function Jebsen hand function test (JHFT)[25], and for finger dexterity Nine Hole Peg Test (NHPT)[26] was administered as an outcome measures. The BBT, ARAT, and JHFT was administered as primary outcome whereas NHPT as secondary outcome. Outcome measures were performed at 0 months (pre treatment) and at 3 weeks (post treatment).

The BBT measures gross manual dexterity[23] and used as a prevocational test for handicapped people.[27] A test box with 150 blocks and a partition in the middle was placed lengthwise along the edge of a standard height table, 150 blocks was in the compartment of the test box on the side of the subjects dominant hand. The number of blocks carried from one compartment to the other in one minute was calculated.[28] The ARAT[24] is a standardized ordinal scale that measures upper-extremity (arm and hand) function. It is a 19-item measure divided into 4 basic movements: grasp, grip, pinch, and gross movements of extension and flexion at the elbow and shoulder which assesses the ability to handle smaller and larger objects with a variety of qualitatively rated items.

The JHT[25]evaluates unilateral hand skills and provides an objective assessment of hand functions involved in activities of daily living. The test includes a series of seven subtests performed with each hand that represent a wide range of tasks involving the upper extremities. The subtests consist of 7 items: writing, simulated page turning, lifting small common objects, simulated feeding, and stacking checkers, lifting large and light objects, lifting large and heavy objects. The subtests are scored by recording the number of seconds required to complete each task. The NHPT[26] was developed to measure finger dexterity, also known as fine manual dexterity. It is composed of a square board with 9 pegs. The manual dexterity was assessed by examining the changes in the speed to complete the NHPT.

Statistical analysis: The data was statistically analyzed using SPSS 22.0 version. All statistical analysis was performed on the final 40 subjects, and there were no missing data. The mean and standard deviation of the data were obtained through descriptive statistics. The data was normally distributed and analyzed by ANOVA. Post Hoc analysis with Bonn-feronni test was used to see inter and intra group changes. F value that is main effect and interaction effect was computed while level of significance was fixed at $p<0.05$.

Result : Total 40 subjects were recruited, out of which 20 were in MI group and 20 in CT group. Mean age in MI group was 39.8±8.5 and in CT group, it was 40.5±7.9. Out of 20 subjects in MI group, 13 were males and 7 were females. In CT group, 11 were males and 9 were females. Demographic and clinical characteristics of the 40 subjects, as well as baseline comparisons of the groups, are presented in table 1. Baseline comparisons revealed that age, gender, time since SCI, type (traumatic/ nontraumatic), MMSE scores, Asia impairment scale grade (AIS) did not differ between the groups. At baseline and after 3 weeks of treatment, subjects of both groups showed statistically significant improvements in all the variables measured (Table 2 and 3). No relevant adverse event was noted during the study in both groups. Table 4 presents the between-group comparisons of the change score for all outcome measures from baseline to post intervention.

Table 1: Demographic Characteristics of the MI with PP and Conventional therapy Group and Baseline Measurements

Variables	MI with PP group n =20	CT group n=20
Age (Years)	39.8 ±8.5	40.5±7.9
Duration (Days)	145.5 ±20.2	148.0 ±20.7
MMSE	27.4 ±1.3	26.8 ±1.7
Gender (M:F)	13:7	11:9
Traumatic/Non traumatic	17/3	19/1
ASIA Neurological level	C5 =5	C5=3
	C6=9	C6=12
	C7= 6	C7= 5
AIS Grade B and C	Grade B =8	Grade B=5
	Grade C=12	Grade C=15

Values are number or mean ± standard deviation, ranges provided for continuous variable MMSE: Mini-mental state examination, AIS: ASIA Impairment Scale,

Table 2 and 3 represents within group mean change at pre and post intervention with significant improvement in all variables for MI and CT group.

Table 2: Pre To Post Changes In MI Group Along With PP After 3 Weeks Of Intervention.

Variables	Pre Intervention		Post Intervention		p value
	Mean ±SD	95% CI	Mean±SD	95% CI	
BBT	7.5±5.7	4.8-10.1	11.7±7.4	8.2-15.2	<0.05
ARAT	20.17±.2	16.7-23.5	26.8±6.3	23.8-29.8	<0.05
JHFT	380.2± 77.3	344.0-416.4	366.4± 79.7	329.1-430.7	<0.05
NHPT	257.1± 43.3	236.8-277.3	235.4± 42.0	215.7-255.1	<0.05

Abbreviations: CI, confidence interval; BBT, Box and Block Test; ARAT, Action reach arm test; JHFT, Jebsen Hand function Test; NHPT, Nine Hole Peg Test

Table 3: Pre To Post Changes In CT Group After 3 Weeks Of Intervention.

Variables	Pre Intervention		Post Intervention		P value
	Mean±SD	95% CI	Mean±SD	95% CI	
BBT	7.2±5.8	4.3-9.9	7.8±5.9	5.0-10.5	>0.05
ARAT	18.1±7.5	14.5-21.6	19.6±7.7	16.0-23.2	>0.05
JHFT	400.7±89.2	358.9-442.4	394.0±88.3	352.7-435.3	<0.05
NHPT	266.6±39.5	248.1-285.0	264.4±39.0	246.1-282.6	<0.05

Abbreviations: CI, confidence interval; BBT, Box and Block Test; ARAT, Action reach arm test; JHFT, Jebsen Hand function Test; NHPT, Nine Hole Peg Test

Table 4 shows more improvement in MI group compare to CT group after 3 weeks of intervention

Table 4: Between –Group Difference In Change Scores For Outcome Measures.

Variables	MI with PP Group Mean difference	CT Group Mean difference	p value	F value
BBT	4.2	0.5	<0.05	12.40
ARAT	6.7	1.5	<0.05	8.840
JHFT	-13.8	-6.6	<0.05	12.744
NHPT	-21.6	-2.2	<0.05	8.515

Abbreviations: BBT, Box and Block Test; ARAT, Action reach arm test; JHFT, Jebsen Hand function Test; NHPT, Nine Hole Peg Test

Discussion: The present study shows that structured protocol used for MI intervention along with PP given for 5 days/week for 3 consecutive weeks has significant improvement in improving gross and fine movements of dominant hand in C-SCI subjects. The more improvement was observed in BBT and ARAT compare to JHFT and NHPT. These findings could be due to numerous cortical processes that involved in actual contraction could be activated during MI which indicates that MI pertains to the same category of processes as those which are involved in programming and preparing actual actions. [29] It has been proposed that MI might be considered as a neuronal process that activates specific brain structures like supplementary motor area, premotor and primary cortices which are of basic importance for the cognitive control and planning of movements. There are also evidences that MI can activate cortico-spinal pathways although no motor output is produced.[30] Other structures involved in MI are cerebellum and the parietal cortex.[31] Focusing on these brain activations specific to MI in subjects with SCI have been reported in a variety of studies (Alkadhi et al., 2005; Müller-Putz et al., 2014; Foldes et al., 2017). Thus, MI enables active stimulation of brain motor areas promoting brain plasticity associated with positive effects on motor performance.[22]

This study findings are in accordance with the findings of Grangeon et al. (2010) where they reported that MI contributed to motor improvements equally as motor execution when integrated into physical therapy in one subject with quadriplegia[32] also Cramer et al. (2007) suggested the positive effects of MI training in subjects with SCI, however behavioral effects were only achieved in limbs that were not completely paralysed. in subjects with paraplegia they reported that brain activations during foot movement imagination was similar to those observed in healthy controls.

Furthermore, based on EEG results Ranganathan et al. (2004) suggested that MI enhances the cortical output signal, which drives the muscle to higher activation levels and increases strength.[33] Additionally, some authors have reported a spread of cortical areas controlling abductor digiti minimi and opponens pollicis during MI of hand movement. This shows that cortical cell responsiveness may increase during MI that allows recruitment of more neural structures when discharging a magnetic pulse.[34]

Well, the involvement of spinal structures is still under debate. Lacourse et al studied the area of stimulation during execution and MI of novel and skilled sequential hand movement. The authors have observed congruence of brain activities between execution and imagery during the different phases of learning. As the participants became more skilled, more functional anatomy congruence was seen. Moreover, the same decrease in cerebellar activation and increased striatal activation in execution at skilled learning phase was seen during MI as well.[35] However, the increase of cortico-spinal excitability is specific to the muscle involved in the imagined movement as given by Fadiga et al.(2004).[30] They found an increase of Motor evoked potential amplitude in the biceps brachii muscle during MI of elbow flexion but not during MI of elbow extension and inversely for the triceps brachii muscle. MI is also influenced by subject's motor skills or environmental factors. Participants with higher MI ability showed a greater increase of the cortico-spinal excitability.

Although there have been limited studies, promising evidence of MI based brain computer interfaces (BCI) efficacy to compensate for inability to grasp is also accumulating. Indeed, participants with C4 and C5 tetraplegia have gradually become able to control a grasping BCI device using extensive MI training of impossible movements (e.g. right, left hand or feet). [36]

Additionally, the most recent studies demonstrated activities of primary motor cortex during MI. This activation was apparent for MI of finger and wrist movements.[16] The present study used structured protocol for hand rehabilitation reveals greater improvement in all the variables as compared to CT group. These findings are in accordance with previous evidence indicating that improvement in hand functions are greater when fine motor practice is performed aimed at increasing cortical excitabilities. It has also been suggested that the plasticity may promote optimal utilization of the remaining pathways conducting neural impulses through the injured regions of the spinal cord in individuals with incomplete SCI.[37]

Study limitations : According to our inclusion criteria, our findings and conclusions are based on the population of C-SCI (all within 6 months post SCI) without cognitive deficits but with severe motor impairment of the hand and upper extremity. A potential limitation of this study is the generalizability of the results that these findings may not be applicable to chronic SCI subjects with different level involvement. Another limitation could be that we have not assessed its long term effect on hand function. Other possible limitations could be lack of follow up at post intervention. As a further limitation of our work we did not use imaging technique to demonstrate brain reorganization after therapy.

Future studies may investigate the effectiveness of MI on SCI subjects with other motor and sensory impairments and mental practice needs to be investigated for the same. Selective technique of MI with PP with structured protocol to be developed also address on its duration, intensity and frequency. Investigate MI with PP as a home treatment because it is simple, inexpensive and easy technique. Lastly, MI should also be compared with other rehabilitation techniques used to treat SCI subjects.

Conclusion: In conclusion, this study found impressive positive effects of MI with PP compared with CT on motor recovery, especially gross manual dexterity and finger dexterity of upper limb, as well as hand function. This study is the first to use structured protocol for upper extremity motor recovery in C-SCI subjects. MI can be used as one of the technique to treat SCI subjects and given as a home exercise.

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Conflict of interest: None
Funding: None
Cite this Article as: Rai P ,Singh P. Effects of Motor Imagery on upper extremity function in subjects with cervical spinal cord injury- A Randomized Clinical Trial. Natl J Integr Res Med 2019; Vol.10(4): 18-25