Contribution of ipsilateral primary motor cortex activity to the execution of voluntary movements in humans: A review of recent studies

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Abstract In primates, unilateral voluntary movements are preferentially controlled by the primary motor cortex (M1) contralateral to the side performing the movement. However, it has been reported that the M1 ipsilateral to the side performing the movement (ipsi-M1) is also activated during unilateral voluntary movements. Recently, studies involving transcranial magnetic stimulation (TMS) or functional magnetic resonance imaging (fMRI) techniques have gradually elucidated the neural mechanisms responsible for modulating ipsi-M1 activity. In particular, the modulation of ipsi-M1 activity is likely to occur in a task-dependent manner, and is also closely associated with advancing age. In addition, ipsi-M1 excitability is suppressed during the acquisition phase of motor learning. Previous studies have suggested that the modulation of ipsi-M1 activity occurs via changes in the activation of the corpus callosum pathways linking the bilateral M1. In this article, we will broadly review the features of ipsi-M1 activity, observed during the execution of unilateral movements, as well as the detailed neural mechanisms underlying the modulation of ipsi-M1 activity. Understanding the role played by ipsi-M1 activity during voluntary movements would improve our knowledge of human motor control systems.

Keywords: ipsilateral primary motor cortex, voluntary movement, task-dependency, corpus callosum, human motor control, motor learning

Introduction

During unilateral voluntary movements involving the upper limbs, the muscles in the upper limbs are predominantly under the control of crossed corticospinal tracts originating from the primary motor cortex contralateral (contra-M1) to the side performing the movement, because approximately 80% of corticospinal fibers cross over to the contralateral side at the pyramidal decussation¹. However, there is a growing body of evidence to suggest that the ipsilateral M1 (ipsi-M1) is also involved in controlling upper limb movements (Fig. 1)².¹¹.

Due to recent developments in neuroimaging, e.g., functional magnetic resonance imaging (fMRI), and neurophysiological techniques, e.g., transcranial magnetic stimulation (TMS), findings regarding the features of ipsi-M1 activity, induced during unilateral movements, and the mechanisms by which ipsi-M1 activity is modulated have been reported since the late 1990s. In brief, TMS is a non-invasive brain stimulation technique in which neurons are temporarily activated using a magnetic coil. A magnetic field is produced within the lines of flux that pass perpendicular to the plane of the coil, which induces eddy currents within the brain. When suprathreshold TMS is delivered over the M1 representation of hand muscles, the magnetic pulse evokes a muscle response in the contralateral hand muscle, which can be recorded using electromyography². Such muscle responses are called motor evoked potentials (MEP). The TMS technique is widely used to assess neurophysiological changes in M1 excitability. On the other hand, fMRI is a non-invasive high spatial resolution mapping method in which MRI signals are used to detect blood flow and oxygen metabolism as a means of measuring the neural activity of the whole brain³,⁴. Ogawa et al.⁵ were the first to demonstrate the blood oxygen level dependent (BOLD) signals that are the basis of the fMRI technique. The blood oxygen levels within particular areas of the brain are remarkably sensitive to the changes in neural activity induced by motor, motor imagery, or cognitive tasks. As with the TMS technique, fMRI has been widely used across a range of research fields to assess brain and spinal activity in humans.

A representative TMS study by Stedman et al.⁷ found that MEPs, induced in a relaxed finger muscle in response to single-pulse TMS of the contra-M1, were increased when the opposite homologous muscle was voluntarily
activated. It is suggested that such increases in the MEPs of relaxed finger muscles probably result from both cortical and spinal activity. In a study using fMRI, Kobayashi et al. reported that during a repetitive unilateral rhythmic movement, activation of both the contra- and ipsi-M1 was detected in half of the participants. According to the studies described above, the execution of unilateral voluntary movements involving the upper limbs is accompanied by an increase in ipsi-M1 excitability. Studies examining the mechanisms responsible for such changes have reported that modulation of the corpus callosum pathways linking both hemispheres or ipsilateral projections to the ipsilateral spinal cord are involved in MEP changes in the opposite limb during the performance of unilateral movements. Very recently, it has been reported that uncrossed descending pathways originating from the ipsi-M1 to the ipsilateral spinal cord play an important role in controlling skilled upper limb movement as well as selective muscle activity in the proximal upper limb.

In addition, clinical evidence has been obtained regarding the contribution of the ipsi-M1 to post-stroke recovery. Specifically, it has been suggested that upregulation of the activity of the contralesional M1 (i.e., ipsilateral to the paretic side) might be important for improving paretic arm function after stroke. These findings indicate that the M1 ipsilateral to the paretic side discharges neural impulses to the paretic limb via either uncrossed descending or corpus callosum pathways on behalf of the ipsilesional M1.

Given the accumulating evidence regarding the effects of ipsi-M1 activity during voluntary movements, we consider that activation of the ipsi-M1 during unilateral voluntary movements is worthy of attention from researchers investigating human motor control systems. The primary goal of this article is to review the contribution of ipsi-M1 activity and the neural mechanisms underlying the modulation of ipsi-M1 excitability during various voluntary movement tasks involving the use of the upper limbs. In addition, we will review the relationship between aging and ipsi-M1 activity and the role played by ipsi-M1 activity in motor learning. Furthermore, we will discuss the functional significance of ipsi-M1 activity during unilateral movement.

**Task-dependent modulation of ipsi-M1 activity**

In recent human TMS studies examining the relationship between simple muscle contractions and ipsi-M1 excitability, it was reported that unilateral isometric muscle contractions of the wrist or finger muscles significantly increase the excitability of the ipsi-M1 for the opposite homologous muscle and that the degree of ipsi-M1 excitability increased with muscle contraction strength.

With regard to muscle contraction type, a previous study assessed the changes in the MEP induced in the relaxed opposite flexor carpi radialis (FCR) during shortening or lengthening muscle contractions of the forearm muscles. As a result, it was found that of the MEP evoked in the relaxed FCR during the lengthening muscle contractions...
exhibited significantly smaller amplitudes than those evoked during the shortening muscle contractions, indicating that muscle contraction type affects ipsi-M1 excitability. Thus, even during the execution of simple muscle contraction tasks, ipsi-M1 excitability is affected by the strength and type of the contractions.

The relationship between the performance of skilled motor tasks involving the finger muscles and ipsi-M1 activation has been established. Morishita et al. assessed ipsi-M1 excitability using single-pulse TMS while right-handed participants transferred small grass balls from one box to another using chopsticks with either their left or right hand. As a result, it was demonstrated that ipsi-M1 excitability was significantly increased during the performance of skilled motor tasks with either the left or right hand, and that the induced ipsi-M1 excitability was significantly increased when the left hand was used to perform the task. In addition, it should be noted that a pseudo-skilled motor task that did not involve the use of chopsticks; i.e., a repetitive fingertip-based grasping movement involving the thumb and the index and middle fingers induced weaker ipsi-M1 excitability than the skilled motor task irrespective of which hand was used. In the latter study, the skilled motor task probably required sensitive motor control of the finger muscles, resulting in the enhancement of ipsi-M1 excitability. Interestingly, as described above the degree of ipsi-M1 excitability induced by the skilled motor task was dependent on which hand was performing the task, indicating that manual dexterity can have a substantial effect on ipsi-M1 excitability.

Using single-pulse TMS, Uehara et al. investigated the modulation of ipsi-M1 excitability during repetitive rhythmic unilateral contractions of a finger muscle, which were paced according to auditory cues. Accordingly, it was demonstrated that ipsi-M1 excitability was modulated in a rhythmic manner and that the modulation was dependent on the frequency of the rhythm itself. In particular, performing the rhythmic muscle contractions at 1 or 3 Hz resulted in increases in ipsi-M1 excitability, while performing them at 2 Hz led to a reduction in ipsi-M1 excitability. The relationship between ipsi-M1 activity and the frequency demands of rhythmic muscle contractions is not yet fully understood; however, in the aforementioned study the accuracy of the rhythmic muscle contractions was assessed by calculating coefficients of variance (CV) for the inter-tap-interval (ITI). The CV observed in the 2 Hz condition was significantly lower than those obtained for the 1 and 3 Hz conditions, indicating that the 2 Hz conditions resulted in rhythmic muscle contractions with low variability. Thus, the modulation of ipsi-M1 excitability induced in response to the rhythmic contractions displayed a similar pattern to the CV of the ITI. This finding indicates that ipsi-M1 excitability is affected by the accuracy of rhythmic muscle contractions.

The effects of motor imagery on ipsi-M1 excitability have also been studied using TMS. As a result, an increase in ipsi-M1 excitability was detected during the execution of a unilateral imagined voluntary movement of the index finger. Furthermore, a relationship was demonstrated to exist between the inhibitory corpus callosal pathways connecting the bilateral M1, i.e., interhemispheric inhibition (IHI), and motor imagery. Specifically, the IHI from the contra- to the ipsi-M1 was significantly increased during unilateral imagined voluntary movement compared with that observed during the resting state (i.e., no imagery).

Thus, the findings of the abovementioned studies indicate that ipsi-M1 excitability is modulated in a task-dependent manner during unilateral voluntary or imagined movement.

Age-related modulation of ipsi-M1 activity

The activity of the ipsi-M1 is closely associated with aging. There is a growing body of evidence that age-associated modulation of brain activity in both hemispheres influences the decline in motor performance and motor deficits seen in elderly people. An fMRI study that compared the findings of younger and elderly participants detected increased ipsilateral activation of the sensorimotor area (SM1), dorsolateral prefrontal cortex (PMd), and supplemental motor area (SMA) in the elderly participants during unilateral passive wrist movement. During unilateral rhythmic movement performed according to a 1 Hz auditory cue or at the maximal possible frequency, the elderly subjects displayed significantly increased ipsilateral activation of the SM1, SMA, Brodmann area (BA) 45, BA5, and BA7 compared with younger subjects. Interestingly, during the performance of a more difficult somatosensory-guided unilateral precision task involving the fingers, the ipsilateral SM1 activity of the younger subjects was significantly greater than that of the elderly subjects. In an electroencephalogram study, elderly subjects exhibited markedly greater activation of the ipsilateral sensorimotor area, i.e., in the low (10-11 Hz) and high (12-13 Hz) alpha bands, than younger subjects during unilateral repetitive finger movement according to a 1 Hz auditory cue. Likewise, it was shown that advancing age was associated with the degree of ipsi-M1 excitability induced during an active motor task. Furthermore, other fMRI-based studies have found that advancing age was accompanied by a reduction in ipsi-M1 deactivation during the performance of active motor tasks. These findings suggest that active motor tasks induce greater ipsi-M1 activity in older subjects.

The age-dependent modulation of ipsi-M1 excitability could be due to age-dependent changes in the activity of corpus callosal pathways. It has been suggested that the fibers of the corpus callosum that connect the bilateral hemispheres contribute to the modulation of ipsi-M1 excitability.
excitability. The corpus callosum is the biggest bundle of white matter in the brain, and the interhemispheric pathways (i.e., interhemispheric inhibition, IHI) that are mediated via this bundle can be assessed using a paired-pulse TMS technique. IHI has two phases, an inhibitory component that depends on the interstimulus interval (ISI) between the conditioning and test stimuli. Previous studies have detected a relationship between the IHI of the bilateral M1 and aging. For example, in one study younger subjects exhibited stronger IHI of the ipsi-M1 during unilateral voluntary muscle contractions than elderly subjects. Likewise, age-related differences in the microstructures of the fiber tracts of the corpus callosum linking the bilateral M1 and the degree of IHI have been reported in studies combining diffusion tensor imaging and TMS techniques. In the younger adults, a positive correlation was detected between microstructural integrity of the fiber tracts of the corpus callosum and IHI, indicating that better corpus callosum tract microstructural integrity leads to the induction of strong IHI. Conversely, the elderly participants exhibited a negative correlation between these factors. In addition, Seidler et al. stated that age-related atrophy of corpus callosum fibers might be associated with this phenomenon because white matter volume reduces with age at a faster rate than gray matter volume. Based on these findings, it could be considered that neural inputs derived from the contra-M1 into the ipsi-M1 that are transmitted via the corpus callosum are attenuated due to the atrophy of the corpus callosum fibers with advancing age, which would account for the greater activation of the ipsi-M1 observed during unilateral voluntary movements in elderly people.

**Contribution of ipsi-M1 activity to motor learning**

It is considered that the M1 plays a key role in the early stages of the acquisition of motor learning. In both humans and animals, motor learning involving the hands or legs leads to alterations in the excitability of the contra-M1 innervating the trained muscle, which is well known as plasticity. However, to the best of our knowledge there is not a lot of information about the details of the relationship between motor learning and ipsi-M1 activity. A human study that used a disruptive TMS technique found that applying TMS over the dominant left M1 resulted in greater disruption of complex ipsilateral unimanual finger tasks than the application of TMS over the non-dominant right M1 in right-handed participants. This indicates that the left M1 is more involved in performing ipsilateral movements than the right M1 in right-handed participants. In other words, the left M1 contributes to ipsilateral motor control systems during the performance of unilateral movements with the left hand, but the right M1 does not make a similar contribution when the right hand is voluntarily activated. Suzuki et al. used a two-ball-rotation task, which could be performed with the right or left hand, to induce motor learning and then examined the resultant changes in ipsi-M1 excitability by recording TMS-induced MEP from the relaxed finger muscles contralateral to the movement side. As a result, it was found that the MEPs induced in the contralateral relaxed finger muscles were decreased after the motor learning task whereas motor performance (the number of ball rotations per 30s) was increased, indicating that the motor learning of unilateral movements suppresses ipsi-M1 excitability. Another study examined whether the suppression of ipsi-M1 excitability via inhibitory repetitive TMS (rTMS), i.e., frequency of 1 Hz for 10 min, improved skilled motor learning in the ipsilateral hand; and it was demonstrated that motor performance (i.e., the key press execution time) was significantly improved by rTMS of the ipsi-M1 prior to the motor learning task compared with the motor performance levels observed in the control (vertex stimulation) and contra-M1 stimulation conditions. These findings could help to explain the relationship between motor learning and ipsi-M1 activity; i.e., they suggest that the downregulation of the ipsi-M1 facilitates the enhancement of contra-M1 excitability and contributes to the motor learning of unimanual tasks, as attenuating the inhibitory inputs from the ipsi- to the contra-M1 via corpus callosum pathways results in reduced ipsi-M1 excitability, which probably makes it easier to induce plasticity in the contra-M1 representation of the trained muscle.

**Contribution of ipsi-M1 activity to muscle synergy**

The selective muscle activity among agonist and antagonist muscles plays an important role in controlling skilled and coordinated movements. In this process, the antagonist muscle is suppressed via the inhibition of the corticospinal tracts innervating it when the agonist muscle is voluntarily activated. As described above, even during the performance of unilateral movements the moving limb is under the control of both M1. However, little detailed information is available about the role of the ipsi-M1 in human motor control, although it is known that the ipsi-M1 predominantly influences the proximal limb rather than the distal limb. Studies involving interventional non-invasive brain stimulation with high-frequency rTMS (i.e., theta burst stimulation, TBS) or transcranial direct current stimulation (tDCS) of the ipsi-M1 have shown that the downregulation of ipsi-M1 excitability induced by these NBS techniques improved muscle synergy in the proximal muscles of healthy participants. In particular, MEPs in the biceps brachii (BB) were facilitated when the participants performed elbow flexion because the BB acts as an agonist during this movement. On the other hand, MEPs in the BB were suppressed when the participants performed forearm pronation because BB acts as an antagonist during this movement. When cathodal tDCS (c-tDCS), which induced inhibitory changes in M1 excitability, was applied over the ipsi-M1 innervating
the BB, MEPs induced in the BB during forearm pronation were selectively suppressed\(^\text{25}\). In addition, in another study involving patients who had suffered stroke the muscle synergy of paralyzed proximal upper limbs was improved by c-tDCS of the ipsi-M1. These findings indicate that ipsi-M1 activity contributes to muscle synergy in the proximal upper limb. Regarding the mechanism by which c-tDCS improves the muscle synergy of proximal muscles, it was proposed that the ipsilateral reticulospinal tract (RST) originating from the ipsi-M1 is probably associated with alterations in muscle synergy that are mediated via propriospinal neurons (PN)\(^\text{21-23}\). Previous animal studies have shown that PN are present at the level of the cervical 3\(^{\text{rd}}\) and 4\(^{\text{th}}\) segments (C3-C4) of the spinal cord. These neurons directly project to the alpha-motoneurons (α-MN) in the forelimb and act as inhibitory or excitatory neurons\(^\text{51,52}\). It has been stated that the C3-C4 propriospinal system plays a key role in controlling visually-guided reaching forelimb movements in animals\(^\text{51}\). Regarding the neural mechanisms underlying the improvements in proximal muscle synergy induced in response to c-tDCS of the ipsi-M1, it was suggested that downregulation of the ipsilateral M1-RST pathways disinhibits the PN, resulting in the suppression of the antagonist BB α-MN before forearm pronation\(^\text{25,23}\).

Mechanisms underlying the modulation of ipsi-M1 activity

It is necessary to consider what types of neural pathways contribute to the modulation of ipsi-M1 activity as well as the changes in the MEP induced in the opposite limb during unilateral voluntary movements. These mechanisms have gradually been clarified by studies involving neurophysiological techniques. With regard to the sites responsible for such phenomena, it was found that during a unilateral rhythmic repetitive movement involving wrist flexion and extension the MEPs evoked in the relaxed opposite wrist muscle by TMS of the M1 were modulated, while the evoked potentials derived from the descending tract at the level of the cervicomedullary junction remained unchanged. In addition, the Hoffman (H-) reflex of the relaxed wrist muscle, which can be used as an indicator of spinal activity, was also modulated by the unilateral rhythmic movement\(^\text{51}\). Another study suggested that MEP facilitation of the relaxed opposite limb probably occurs at both the cortical and subcortical levels\(^\text{8}\). On the other hand, no excitability changes in the anterior horn cells of the spinal cord, which can be assessed using F-waves, were detected during the performance of unilateral rhythmic index finger abduction at around 10% of maximal voluntary contraction (MVC)\(^\text{8}\). In addition to this finding, the F-waves induced in the relaxed opposite first dorsal interosseous (FDI) muscle during unilateral isometric contraction of the FDI at 10 or 30% MVC did not differ from those observed during the resting state of both arms\(^\text{18}\). Another possible explanation provided information regarding the involvement of the cortical level showing that the neural circuits of short- (SICI) and long- (LICI) interval intracortical inhibition are mediated by cortical interneurons via γ-aminobutyric acid (GABA)\(^\text{14,56}\) and do not directly converge on the corticospinal tract\(^\text{57}\). In addition, it has been shown that administering a conditioning stimulus over the M1 at subthreshold intensity to activate these inhibitory circuits did not modulate the H-reflex in the wrist flexor muscle\(^\text{54}\). These findings indicate that the modulation of intracortical circuits occurs at the cortical level. Several studies assessing the SICI and LICI circuits have shown that unilateral voluntary movements resulted in significant modulation of the SICI or LICI within the ipsi-M1\(^\text{12,58}\). Taken together, there is no doubt that changes in the MEP induced in the opposite limb originate from the cortical level; however, we are not able to completely rule out the involvement of subcortical level pathways. Thus, compatible activation of both the cortical and subcortical regions is probably involved in this phenomenon, which might be dependent on the type of task being performed (i.e., fine motor or ballistic tasks) and/or the strength of the muscle contraction involved.

With regard to the relationships between ipsi-M1 activity and IHI, we recently reported that unilateral isometric voluntary index finger abduction led to an increase in ipsi-M1 excitability and a significant increase in short-latency IHI (SIHI) from the contra- to the ipsi-M1; i.e., IHI was significantly increased when an ISI of 10 ms was employed, but no such increase in long-latency IHI (LIHI) was observed, and IHI was not increased when an ISI of 40 ms was used\(^\text{19}\). These findings indicate that SIHI from the contra- to the ipsi-M1 affects ipsi-M1 excitability (Fig. 2). Another study assessing the modulation of SIHI during a fine motor task (i.e., using chopsticks) reported that both SIHI from the contra- to the ipsi-M1 and ipsi-M1 excitability were increased. Interestingly, both of the abovementioned studies detected significantly increased ipsi-M1 excitability together with strong IHI from the contra- to the ipsi-M1 during these tasks. One interpretation of these results is that interhemispheric inputs from the contra-M1 might not project directly to the corticospinal output neurons within the ipsi-M1. Using a triple-pulse TMS paradigm, it was established that even during the resting state, SIHI inhibited SICI within the M1 of the test stimulus side (Fig. 3)\(^\text{59}\). Given that SIHI from the contra- to the ipsi-M1 inhibits SICI within the ipsi-M1, it is conceivable that this inhibition of SICI results in the facilitation of ipsi-M1 excitability during the performance of unilateral movements\(^\text{10,18,29}\).

With regard to the relationship between sensory systems and ipsi-M1 activity, previous studies have examined whether peripheral afferent inputs produced by electrical stimulation of the unilateral ulnar nerve can alter ipsi-M1 excitability, as assessed by single-pulse TMS. As a result, it was found that muscle spindle-derived afferent inputs altered ipsi-M1 excitability in a manner that was depen-
dent on the frequency of electrical stimulation. Although this study did not completely explain the detailed neural mechanisms underlying the modulation of the ipsi-M1 excitability induced by unilateral afferent inputs, it was demonstrated that marked modulation of ipsi-M1 excitability occurred 35 ms after electrical stimulation of the unilateral ulnar nerve. This finding can be interpreted as indicating that afferent inputs from the peripheral limbs take around 20-25 ms to reach the contralateral somatosensory area, and that short latency inhibition of the interhemispheric pathways linking the bilateral M1 extends this period by around 10 ms. Given that peripheral electrical stimulation during TMS stimulation of the ipsi-M1 resulted in significant modulation of ipsi-M1 excitability after 35 ms (25 ms + 10 ms), afferent inputs transmitted via the short latency corpus callosum pathways might be involved in the modulation of ipsi-M1 excitability.

It should be noted that the M1 for distal muscles, i.e., finger muscles, and proximal muscles, and for the triceps brachii (TB), project different levels of SIHI. In particular, significant SIHI was observed from the M1 for the finger and BB muscles, but was not observed for the TB in the same individuals. Thus, in the case of proximal muscles, corpus callosum pathways might not be responsible for modulating ipsi-M1 activity.

The neural inputs that converge in the ipsi-M1 arise not only from the contral-M1, but also from contralateral motor-related areas, e.g., the dorsal premotor area (PMd), ventral premotor area (PMv), and supplementary motor area (SMA), and are transmitted via corpus callosum pathways. Anatomical studies involving non-human primates have found that the interhemispheric callosal connections in the M1, SMA, PMd, and PMv excite homotopic areas in the opposite hemisphere. A recent study in which a paired-pulse TMS paradigm was used to assess connectivity between the contralateral PMd (conditioning stimulus) and the ipsi-M1 (test stimulus) during unilateral rhythmic muscle contractions performed according to three different auditory cues (1, 2, and 3 Hz) demonstrated that PMd-M1 connectivity was modulated by the frequency demand of the contractions. Furthermore, this modulation was consistent with the modulation of ipsi-M1 excitability, indicating that ipsi-M1 excitability might be modulated by neural inputs from the contralateral PMd.

**Functional significance of ipsi-M1 activity during voluntary movement.** An fMRI study by Loibl et al. demonstrated that the M1 for distal muscles, i.e., finger muscles, and proximal muscles, and for the triceps brachii (TB), project different levels of SIHI. In particular, significant SIHI was observed from the M1 for the finger and BB muscles, but was not observed for the TB in the same individuals. Thus, in the case of proximal muscles, corpus callosum pathways might not be responsible for modulating ipsi-M1 activity.

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**Fig. 2** Schematic illustration of the functional differences between SIHI and LIHI targeting the ipsi-M1 during complete rest in both arms (i.e., the resting state) and unilateral muscle contraction. In the resting state, SIHI and LIHI were observed (solid lines). On the other hand, during unilateral muscle contraction, strong SIHI from the contralateral to the ipsi-M1 was observed (boldsolid line), but LIHI was not (dashed line). Abbreviations: M1: primary motor cortex, IN: interneurons, CS: conditioning stimulus, TS: test stimulus, PTN: pyramidal tract neuron.
performed as well as the demands of the task, the ipsi-M1 directly or indirectly contributes to human motor control during the performance of unilateral voluntary movements. However, further study is required to improve our understanding of the functional significance of ipsi-M1 activity.

Hübers et al. used a TMS paradigm to investigate the functional significance of ipsi-M1 activity. In particular, they examined whether unwanted muscle activity (i.e., mirror activity, MA) of the opposite limb during unilateral muscle contractions is associated with IHI from the contra-(i.e., active M1) to the ipsi-M1 (i.e., resting M1) \(^65\). As a result, they found that the magnitude of the IHI targeting the ipsi-M1 was negatively correlated with MA, i.e., participants who exhibited little MA displayed strong IHI and vice versa. This novel finding might be indicative of another functional role of ipsi-M1 activity; i.e., as well as suppressing ipsi-M1 activity, inhibitory inputs converging on the ipsi-M1 via corpus callosum pathways might prevent increases in MA in the opposite limb.

Conclusions

In this article, we reviewed and discussed the findings of previous studies that examined ipsi-M1 activity induced in humans during active tasks involving unilateral limb movements from neurophysiological and neuroim-
aging viewpoints. As discussed, these studies detected increased ipsi-M1 activity during unilateral movement tasks, and the degree of this activity was task and age-dependent. It has been demonstrated that IHI targeting the ipsi-M1 is one of the mechanisms underlying the modulation of ipsi-M1 excitability. With regard to the functional significance of ipsi-M1 activity, although a few studies have suggested that ipsi-M1 activity plays functional roles during unilateral movements and the motor learning of unimanual tasks, these roles are not yet fully understood. These points should be clarified in future studies. Improving our understanding of the contribution of ipsi-M1 to human motor control is important for designing appropriate rehabilitation or sport exercise programs aimed at improving patients’ motor abilities.

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