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# Interlimb neural coupling: Implications for poststroke hemiparesis

## *Le couplage neuronal inter-membres : implications pour l'hémiparésie suite à un accident vasculaire cérébral*

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**Abstract**

Interlimb coordination is essential to perform goal-directed daily tasks and purposeful locomotion. The coordination occurs due to spatiotemporal coupling of movements, which also comprises interactions in segmental kinematics, joint dynamics, and muscle activity. Neuroanatomical and neurophysiological linkages at the spinal and brain level are responsible for the coordination. The linkage is termed ''neural coupling''. According to the task demand, the coupling may occur between two upper limbs or two lower limbs or all four limbs. Central pattern generators play a key role in interlimb coordination by regulating the rhythmic upper and lower limb movements. Neuroanatomically, multiple areas of both cerebral hemispheres via the corpus callosum interact and control the bimanual upper limb movements. There is an interhemispheric synchronization and disinhibition to control the coupled bimanual upper and lower limb movements. Movement of the upper limb also enhances neuromuscular recruitment of the lower limb. In stroke, bimanual motor impairments exist in the form of asymmetry and reduced coordination, which may be related to weakness of the ipsilateral body side lesser than the contralateral side. The aim of the present review was to understand the interlimb coordination and neural coupling and its implication in stroke rehabilitation. The review suggests incorporating the movements of bilateral upper and lower limbs either simultaneously or consecutively for hemiparetic subjects. Further, the conventional and contemporary rehabilitation methods need to be reconsidered while utilizing the coupling concept.


*Keywords:* Bimanual task; Coupled movement; Interlimb coordination; Interhemispheric communication; Neural coupling; Stroke rehabilitation

**Résumé**

La coordination inter-membres est essentielle pour l'exécution de tâches dirigées vers un but de la vie quotidienne et pour une locomotion déterminée. La coordination est le résultat d'un couplage spatio-temporel des mouvements, ce qui inclut également des interactions de la cinématique segmentaire, la dynamique articulaire et l'activité musculaire. La coordination est assurée par des liaisons neuro-anatomiques et neurophysiologiques au niveau spinal ainsi qu'au niveau cérébral. Cette connexion est appelée couplage neuronal. En fonction de la tâche demandée, le couplage peut se produire entre les deux membres supérieurs ou les deux membres inférieurs, ou alors les quatre membres. Les générateurs de patrons centraux jouent un rôle clé dans la coordination inter-membres en régulant les mouvements rythmiques des membres supérieurs et inférieurs. Sur le plan neuro-anatomique, de nombreuses zones des deux hémisphères cérébraux interagissent par l'intermédiaire du corps calleux et contrôlent les mouvements bimanuels des membres supérieurs. Il existe une synchronisation et une désinhibition inter-hémisphérique permettant de contrôler les mouvements couplés bimanuels des membres supérieurs et inférieurs. Le mouvement d'un membre supérieur stimule également le recrutement neuromusculaire d'un membre inférieur. Dans le cas d'un accident vasculaire cérébral (AVC), des déficiences motrices d'ordre bimanuel se manifestent sous la forme d'une asymétrie et d'une coordination diminuée qui peuvent être liée à la faiblesse du côté ipsilatéral du corps, moins diminué que le côté controlatéral. L'objectif de notre article de synthèse est de comprendre la coordination inter-membres et le couplage neuronal et ce que cela implique pour la rééducation après un AVC. L'article suggère d'ajouter des

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mouvements des membres supérieurs et inférieurs bilatéraux soit simultanément, soit consécutivement dans la rééducation des sujets hémiparétiques. De plus, les méthodes conventionnelles et contemporaines de rééducation devraient être revues en tenant compte du concept de couplage.


*Mots clés :* Tâche bimanuelle ; Mouvement couplé ; Coordination inter-membres ; Communication inter-hémisphérique ; Couplage neuronal ; Rééducation après AVC

## 1. English version

### 1.1. Introduction

Interlimb coordination is an outcome of spatiotemporal coupling of movements that occur between the four limbs. Goal-directed daily tasks need skillful bimanual coordination of both the upper limbs [1,2]. Human locomotion also needs modulated interlimb coordination between all the four limbs [3,4]. The neural coordination between the limbs may be referred to as neural coupling. A task-dependent neural coupling of the upper and lower limbs enables the arms to couple during gait but the same gets decoupled during voluntary arm and leg movements [5]. Thus, the coordination can also be considered an ability to sustain a context- and phase-specific recurring association between different body parts and joints in spatiotemporal dimensions [6].

Central pattern generators (CPGs), a functional network of spinal neurons, coordinate and regulate the rhythmic movements of arms and legs during locomotion [4,7–9]. Neural mechanisms are common across similar rhythmic tasks such as walking and stepping [10]. Neural coupling exists for the spatiotemporal dimensions of movement. CPGs and the dominant brain hemisphere regulate the temporal aspect; whereas the corpus callosum controls the spatial attribute of movement [11]. Thus, distributed brain areas are responsible for task-specific interlimb coordination [12–16].

A neural cross-talk exists between two brain hemispheres to communicate for a coordinated movement pattern. The coupling between two sides of the brain constrains and modulates the task-specific actions in a different environmental context [17–19]. There is an interhemispheric synchronization that controls coupled bimanual movements for both the upper and lower limbs [1,20]. Coordinated bimanual movement is the result of the suppression of interference between two hemispheres. Such coupling between the hemispheres has an important role during learning a novel bimanual task such as playing the piano [21].

The upper limbs interact with the lower limbs contextually during standing and walking [12]. For instance, both catching a ball in the standing position and walking while carrying a bag require different interactions between the limbs. Rhythmic movements of the upper limbs enhance the lower limb neuromuscular recruitment [22–24]. The limbs exhibit task-specific, skilful, and efficient interlimb coordination. However, the coordination is impaired during either nonfunctional or single limb performance [25].

The distributed network of neuronal synchronization and desynchronization is responsible for disrupting the interlimb coordination in conditions such as poststroke hemiparesis [12]. Poststroke subjects retain a close interaction between the affected and less-affected sides; however, there is a reduction of interlimb movement patterns during bimanual performance [5,26]. The altered movement pattern leads to bimanual asymmetries and task-specific impairments. The impairments warrant intervention to induce better motor and functional recovery than that achieved by the existing method [27].

Interlimb neural coupling persists even after a stroke. Hence, the coupling and spinal contribution for rhythmic movements can be utilized in stroke rehabilitation [28–31]. The rehabilitation may incorporate bilateral upper and lower limbs movements simultaneously or consecutively to facilitate interlimb coordination [22]. Repetitive bimanual coordinated movements may enhance motor function and encourage activity-dependent neural plasticity [32–35]. The objective of the present review was to understand the interlimb coordination and neural coupling and its implication in poststroke hemiparesis.

### 1.2. Neural coupling and interlimb coordination

Interlimb coordination, an important aspect of motor control, is achieved through spatiotemporal coupling of limb movements [1–4]. It is an interaction in segmental kinematics, joint dynamics, and muscle activity. In other words, it refers to the movements that require rhythmic, sequential and simultaneous use of both the body sides. It may be classified into bimanual coordination and hand-foot coordination. Bimanual coordination is a skilled interlimb coordination of two arms in any bimanual task. It also requires intra- and interlimb coordination (integration and sequencing of action within and between the limb/s, respectively) for a successful task performance. For example, throwing a large ball, and using the fork and knife simultaneously for eating [36,37]. Hand-foot coordination is a simultaneous coupling of either the ipsilateral or contralateral side or both the body sides; for instance, the use of hands and feet during driving a car. Thus, interlimb coordination is a repertoire of skills ranging from simple daily activities to complex coordinated tasks. The neural coupling exists despite biomechanical constraints [38].

Interlimb coupling exists from the prenatal period to childbirth and it is transformed from reflexive to goal-directed and voluntary movement during further development [29]. An infant exhibits interlimb neural coupling in the form of mirror