CHAPTER 1

Introduction

1.1 DEFINITION OF TREMOR

Tremor is defined as a rapid back-and-forth movement of a body part (McAuley and Marsden, 2000). Tremor is one of the most common movement disorders encountered in clinical practice and is a readily apparent motor phenomenon in most instances. It occurs both in normal individuals (the so-called physiological tremor) and as a symptom of a disorder, most often of neurological origin.

Pathological tremor is usually a rhythmic and roughly sinusoidal oscillatory movement. However, tremor is a nonlinear and nonstationary phenomenon. It is distinct from other involuntary movement disorders such as chorea, athetosis, ballism, tics, and myoclonus (see Table 1.1) by its repetitive and stereotyped feature (Bhidayasiri, 2005). The different tremors are grouped according to their frequency, amplitude, topographical distribution, and task or position-dependence. The most commonly used clinical classification is to distinguish tremor into *rest tremor*, *postural tremor*, and *kinetic tremor* (see also Chapter 4 for the clinical characterization).

1.2 PHYSIOLOGICAL TREMOR

In physiological tremor, two distinct oscillations (mechanical reflex and central neurogenic) are superimposed upon a background of irregular fluctuations in muscle force and limb displacements (Elble, 1996, 2003). Frequency studies show, in the majority of cases, similar frequencies on both sides.

The *mechanical reflex component* is the largest of the two oscillations. Its frequency is governed by the inertial and elastic properties of the body (Elble, 1996). Damped oscillations are generated in response to pulsatile perturbations, such as those produced by irregularities in motor unit firings (a motor unit includes a motoneuron and the depending muscle fibers, see Chapter 2) and by blood ejection during cardiac systole.

The frequency (ω) of these passive mechanical oscillations depends directly upon the stiffness (K) of the joint and inversely upon the inertia (I) according to the equation:

$$\omega = \sqrt{(K/I)}.$$

TABLE 1.1: Differential diagnosis of involuntary movements

INVOLUNTARY MOVEMENTS	DEFINITION/FEATURES	DISEASES COMMONLY ASSOCIATED WITH THE MOVEMENT DISORDER
Tremor		
Rest	See text	Parkinson's disease
Postural		Essential tremor
Kinetic		Cerebellar tremor
Dystonia	Prolonged muscle contractions leading to abnormal postures; may be repetitive; twisting movements	Drug-induced
		Genetic
		Idiopathic
Chorea	Irregular; often hidden in voluntary movement; generates a dance-like movement	Huntington's disease
Athetosis	Continuous slow hyperkinesia of distal segments of limbs; causes an octopus-like movement	Stroke
Ballism	Fast and ample movement of proximal segments of limbs; gives a "throw away"-like movement; more severe in upper limbs	Stroke
		Inflammatory diseases
Tics	Fast and short hyperkinetic movements usually with a facial or head topography	Gilles de la Tourette syndrome
Myoclonus	Sudden, short (20–150 ms) movement; may cause a pseudorepetitive muscular contraction	Essential myoclonus
		Myoclonic epilepsy
		Symptomatic myoclonus

Consequently, tremor frequency will increase from proximal to distal segments. Physiological tremor of the elbow has a frequency of 3–5 Hz, wrist tremor 7–10 Hz, and metacarpophalangeal joint tremor 12–30 Hz (Elble, 2003).

The *central neurogenic component* of physiological tremor is invariably associated with the modulation of motor unit activity. Rhythmic motor unit activity is not just a simple passive response to sensory feedback, but is driving the limb oscillation. Moreover, regardless of their mean frequency of discharges, participating motor units are entrained at about 8–12 Hz. The frequency of the central neurogenic tremor shows no response to modification of inertia or stiffness and is independent of the length of the stretch reflex. For these reasons, the central neurogenic tremor is believed to originate from an oscillating neuronal network within the central nervous system (Elble, 1996).

The normal tremor behavior when an inertial load is added to the limb is a decrease of frequency, according to the equation $\omega = \sqrt{(K/I)}$, when there is no significant contribution from the stretch reflex or central oscillations. This is confirmed by surface or needle electromyographic (EMG) studies showing no rhythmic motor unit entrainment despite the rhythmic oscillations of the limb (Figure 1.1a). In some subjects, a prominent motor unit entrainment with and without mass loading is identified (Figure 1.1b). In pathological cases (for instance, essential tremor, see Chapter 5), lower- and higher-frequency oscillations can be identified. These last ones are associated with motor unit entrainment and do not decrease with inertial loading. For these reasons, high-frequency oscillations are interpreted as central neurogenic oscillations, whereas low-frequency oscillations correspond to the mechanical reflex resonance frequency (Elble, 2003).

In addition to the 8- to 12-Hz frequency band, frequency oscillations in the 15- to 30-Hz range and around 40 Hz are commonly found in the kinematic and EMG recordings in the upper limbs. Based on the fact that changes in the amplitude of specific frequency bands of tremor as a function of added mechanical load are informative of the central or peripheral modulation of tremor, some authors have studied the effects of increments of load on the intensities of the 8- to 12-, 20- to 25-, and 40-Hz neural rhythms (Vaillancourt and Newell, 2000). Their findings support the view that the 8- to 12-Hz oscillation resides within the central nervous system with its amplitude remaining independent of mechanical resonance oscillations and that the 20- to 25-Hz tremor oscillations are related to the mechanical properties of the finger. This means that the 20- to 25-Hz band is related to cortical activity, but its amplitude is modulated by mechanical reflex oscillations. Concerning the 40-Hz peak found in EMG recordings, it is likely originating in the central nervous system before being low-pass filtered by the muscle–tendon complex. The tendency of human limb segments to exhibit rhythmic oscillations around 40 Hz is observed in EMG recordings during strong voluntary contractions (“Piper rhythm”; Piper, 1907). Data of surface EMG traces simultaneously recorded with magnetoencephalographic signals (see Chapter 6) suggest that Piper rhythm of human muscles is linearly correlated with focal activity in the controlateral motor cortex both in

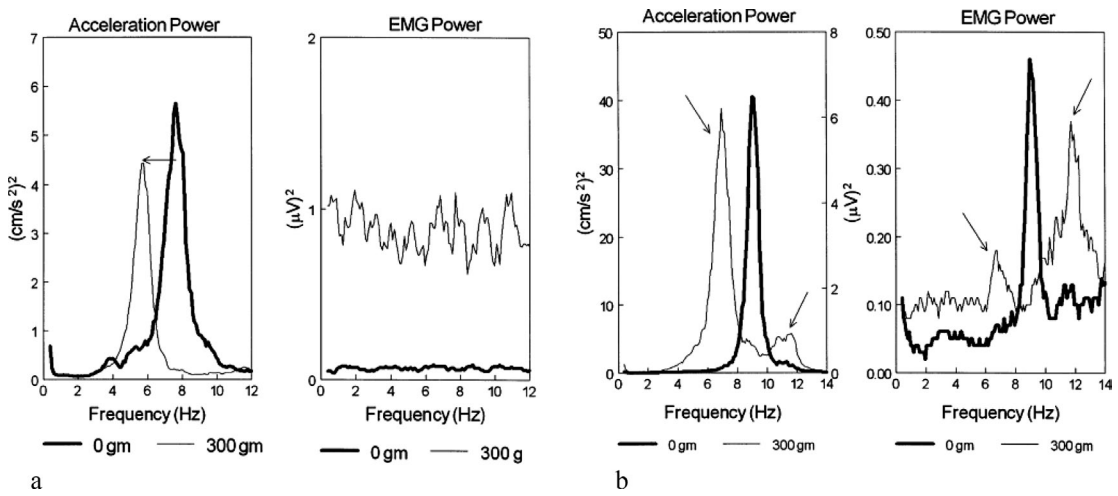

FIGURE 1.1: (a) Wrist tremor and rectified–filtered electromyography (EMG; Extensor carpi radialis bilateral: ECRb) from a 27-year-old woman with no evidence of motor unit entrainment without (thick trace) and with 300-g loading (thin trace). Note the 2-Hz reduction in the acceleration spectral peak with 300-g loading (arrow). (b) Wrist tremor and rectified–filtered EMG (ECRb) from a 21-year-old man with prominent motor unit entrainment with and without mass loading. With no mass loading, the acceleration and EMG spectra contained a single coherent peak at 9.4 Hz. Mass loading produced coherent peaks in the EMG and acceleration spectra at 6–7 and 11–12 Hz (arrows). Left vertical axis of the acceleration spectrum: 0-g load; right vertical axis: 300-g load. From Elble (2003), with permission from Elsevier.

isometric contractions and during phasic movements. A longer lag to tibialis anterior than that to forearm extensor muscle may be detected. This interval is linked to the conduction in fast pyramidal pathways (see Chapter 2). Because Piper rhythm can be picked up from most muscles, including those with few or no muscle spindles, it is unlikely that the coherence between cortical activity and the Piper rhythm is due to a simple reafference mechanism. Piper Rhythm is related to the degree of force exerted in tonic and phasic contractions probably because of a stronger excitation of the motor cortex during forceful contractions. Alternatively, it may be related to a greater attention demand in tasks requiring forceful contraction (Brown et al., 1998).

1.3 SOURCES OF TREMOR: NEURONAL NETWORKS

We can thus summarize the sources of tremor into three groups (Figure 1.2; Hallet, 1998):

I—Mechanical oscillations: Motion of joints and muscles obey the laws of physics, and tendon–muscle–joint complexes can be compared with masses and springs. Therefore, oscillations can be interpreted as related to movements of these masses and springs (Figure 1.3).

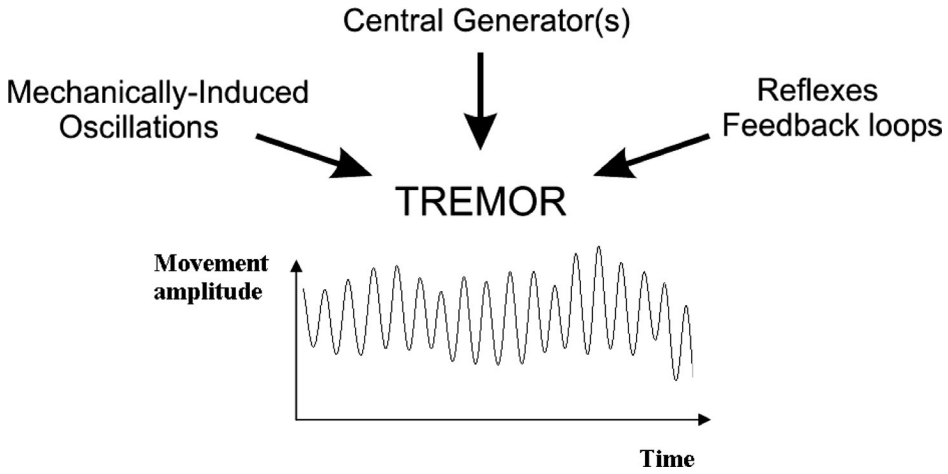

FIGURE 1.2: The three main sources of tremor.

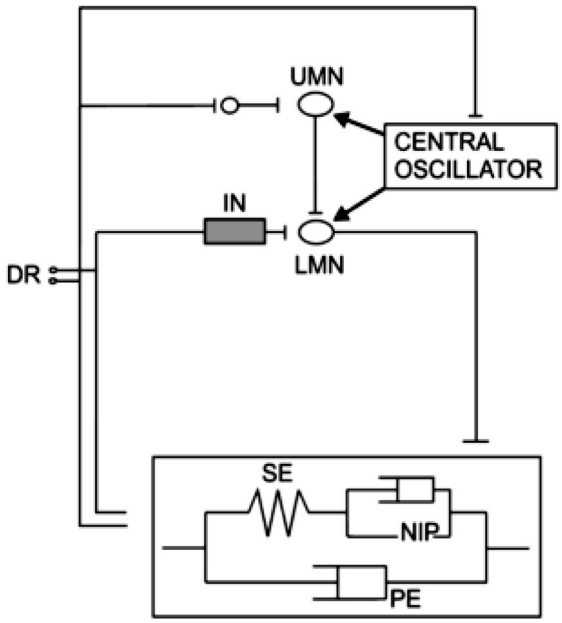

FIGURE 1.3: Central and peripheral loops in the nervous system. The figure illustrates the interaction between the central oscillator and the upper motoneuron (UMN)/lower motoneuron (LMN). IN indicates the pool of interneurons in the spinal cord. DR corresponds to the dorsal root ganglia. The rectangle in the bottom represents Hill's muscle model (SE: series elastic component; NIP: neural input processor in parallel with a viscous component PE).

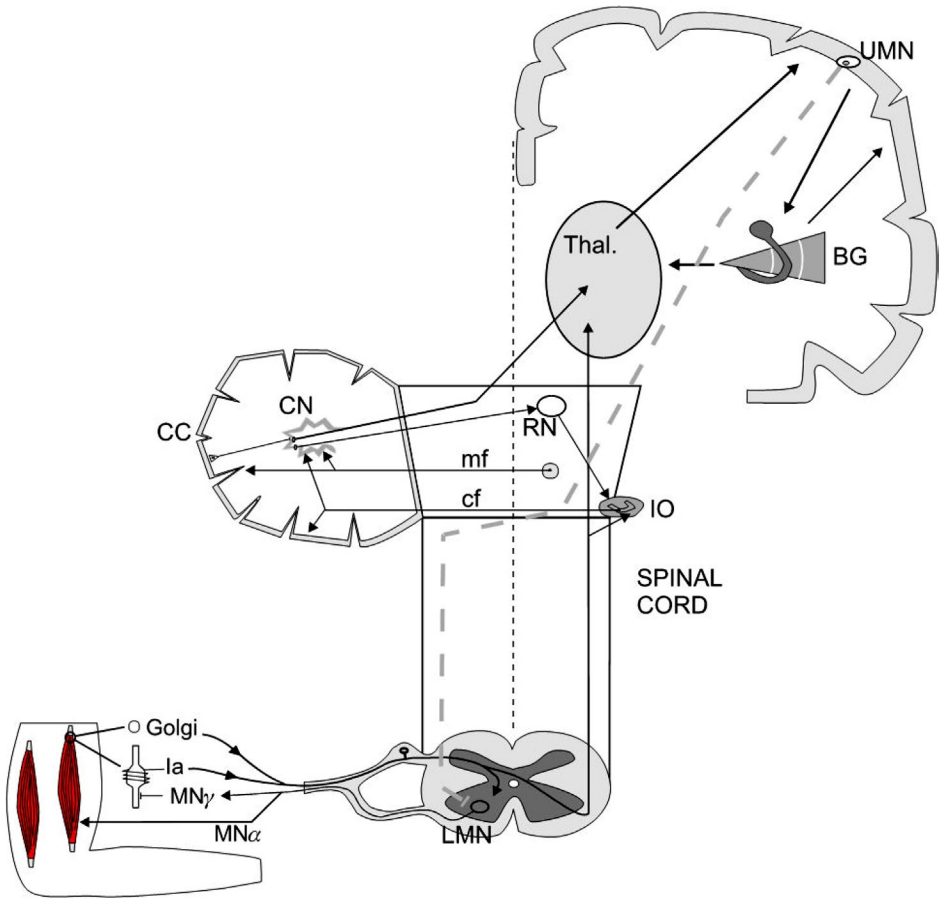

FIGURE 1.4: Pathways involved in tremorgenesis. Muscle spindles are receptors located inside muscles, made up by fibers sensitive to changes in length. In response to lengthening, the signals reach spinal and supraspinal centers where motor commands are generated and sent back to the extrafusal muscle fibers. UMN: upper motoneuron; Thal: thalamus; BG: basal ganglia; CC: cerebellar cortex; cf: climbing fibers; mf: mossy fibers; CN: cerebellar nuclei; IO: inferior olive; LMN: lower motor neuron; MNα: alpha motoneuron; MNγ: gamma motoneuron; RN: red nucleus; Ia: Ia sensory afferent fibers. Note that afferents project to the cerebellum ispilaterally.

II—Reflex oscillations: They are related to loops: *peripheral loops* from muscles to the spinal cord and back again (spinal level) and *central loops* from the periphery to the spinal cord and segments at the supraspinal level including the brainstem, cerebellum, basal ganglia, and cerebral cortex (Figures 1.3 and 1.4).

- The simplest loop is from the muscle spindle. Ia afferents are connected monosynaptically to the motoneuron, and the motor axon projects to the extrafusal muscle fibers.
- A classical example of a central loop is given by the role of comparator and movement controller of the cerebellum.

III–Central oscillations: Since the first electroencephalographic (EEG) recordings, it is obvious that the neural activity follows rhythmic behaviors. Cerebral cortex, basal ganglia, cerebellum, and brainstem nuclei are all involved in tremogenesis (see Chapter 3).

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