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# Effects of proprioceptive neuromuscular facilitation on the initiation of voluntary movement and motor evoked potentials in upper limb muscles

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## Abstract

To better understand the mechanisms behind proprioceptive neuromuscular facilitation (PNF), an important method in motor rehabilitation, we investigated the effects of assuming a PNF posture relative to a neutral posture on the initiation of voluntary movement (Experiment 1) and the excitability of the motor cortex (Experiment 2) using a wrist extension task. The initiation of voluntary wrist movement was operationalized in terms of the electromyographic reaction time (EMG-RT), and the excitability of the motor cortex in terms of motor evoked potentials (MEPs). Compared to the neutral position, we found that (1) the facilitation position changed the muscle discharge order enhancing the movement efficiency of the joint, (2) the facilitation position led to a reduction in EMG-RT, the magnitude of which depended on the proximity of the muscle to the movement joint, and (3) MEP amplitude increased and MEP latency decreased in the facilitation position as a function of the proximity of the muscle to the joint. These findings corroborate the presumed effects of PNF and provide insights into the neurophysiological mechanisms underlying the PNF method. © 2002 Elsevier Science B.V. All rights reserved.

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## **1. Introduction**

It is well known that the initiation of voluntary movement is influenced by limb position changes prior to the start of the movement (Nakamura, Taniguchi, Narabayashi, & Yokochi, 1979; Nara & Kasai, 1991; Taniguchi, Nakamura, & Kasai, 1984; Taniguchi, Nakamura, Yokochi, & Narabayashi, 1980). One reason for this is that the prime mover – the main effector of a particular voluntary movement – changes its length in accordance with the limb position changes. Sensory inputs from peripheral organs, such as muscle spindles, thus influence motor output mechanisms of the central nervous system (CNS) (Condon & Hutton, 1987; Etnyre & Abraham, 1986; Guisard, Duchateau, & Hainaut, 1988; Mark, Coquery, & Paillard, 1968; Moore & Hutton, 1980; Moore & Kukulka, 1991; Robinson, McComas, & Belanger, 1982; Romano & Schieppati, 1987; Smith, Hutton, & Eldred, 1974; Weiss, Kearney, & Hunter, 1986). During the last decade, many unexpected properties of the activity of muscle spindle afferents and fusimotor efferents have been reported. During normal isotonic movements and limb position changes, the ensemble of spindles within a muscle dynamically signals a slightly distorted version of muscle length (Prochazka, Gorassini, & Taylor, 1992). The gain of this signal is modulated by fusimotor action, which appears to be strongly task- and posture-dependent. That is, the stretch-sensitivity of muscle spindles depends on fusimotor action and is a function of muscle length.

Furthermore, limb position changes prior to voluntary movement affect the combination of muscles involved in the activity and the order in which they are activated (Furubayashi & Kasai, 1990). The importance of initial limb position for executing movements has been emphasized in motor rehabilitation by advocates of the proprioceptive neuromuscular facilitation (PNF) technique. PNF is a therapeutic intervention used in rehabilitation which was originally developed to facilitate performance in patients with movement deficits. A variety of methods fall under the rubric of PNF, including the exploitation of postural reflexes, the use of gravity to facilitate movement in weak muscles, the use of eccentric contractions to facilitate agonist muscle activity, and the use of diagonal movement patterns to facilitate the activation of bi-articular muscles (de Vries, 1962; Etnyre & Lee, 1987; Hardy, 1985; Hardy & Jones, 1986; Hartley-O'Brien, 1980; Holt, Travis, & Okita, 1970; Lukas & Koslow, 1984; Osternig, Robertson, Troxel, & Hansen, 1987; Sady, Wortman, & Blanke, 1982; Snyder & Forward, 1972; Tanigawa, 1972).

In the present study we investigated how the PNF method affects the initiation of voluntary movement and the momentary coupling of the activities of several muscles. Special attention was paid to the analysis of neurophysiological mechanisms using changes in arm position as an example. In order to be able to examine these neurophysiological mechanisms also at the cortical level, we employed the transcranial magnetic stimulation (TMS) method (Barker, Jalinous, & Freeston, 1985). Motor evoked potentials (MEPs) induced by the initiation of voluntary movement were recorded after limb position changes. Neurophysiological mechanisms related to the PNF method were evaluated on the basis of the observed changes in latency and amplitude of the MEP. Preliminary accounts of this study were previously reported at a conference (Shimura & Kasai, 1999).

## 2. Experiment 1

In this experiment we investigated the effectiveness of PNF by considering the effects of limb position changes on the initiation of human voluntary movement in terms of electromyographic reaction times.

### 2.1. Methods

#### 2.1.1. Subjects

All subjects ( $n = 7$ ; all male, 38–43 years old) gave informed consent in accordance with local institutional guidelines and the ethical standards laid down in the 1964 Declaration of Helsinki. The experiment was conducted in a quiet laboratory room.

#### 2.1.2. Procedure

Fig. 1 shows the two upper arm positions used in this study, a neutral position N (Fig. 1(A)) and a position facilitating activity of the upper extensor muscles, abbreviated PNF (Fig. 1(B)). The effects of these positions on EMG-RTs and EMG discharge order were considered. The subject could passively adopt the two upper arm positions using his right (preferred) arm by means of especially made arm holders. For each arm position, six blocks of 10 trials were performed. All trials of the first block and the first trial of each of the following blocks were excluded from the analysis to eliminate start-up effects. In addition, a few trials were discarded because of obvious mistakes in the recording.

After the experimenter had said “Ready!”, the subjects were instructed to extend their right wrist as quickly as possible (simple reaction time task) upon hearing a

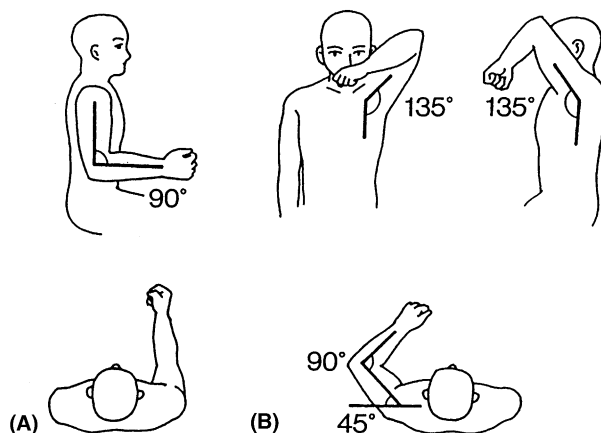


Fig. 1. Schematic representation of the neutral (N) limb position (panel A) and the facilitatory (PNF) limb position (panel B).

high pitched tone of 100 millisecond duration which was given at random time intervals.

EMGs were recorded simultaneously from three muscles (m. brachioradialis: B; m. triceps brachii: T; and m. deltoideus: D) using 3 cm diameter, bipolar, silver–silver surface electrodes connected to an EMG-unit (NIHONKOHDEN, AB-620G, band-pass 5Hz–3kHz). After AD-conversion of the signals, EMG onsets were determined by the experimenters by means of visual inspection. This procedure was based on criteria formulated in previous reports (Furubayashi & Kasai, 1990; Kasai & Seki, 1992). From these estimates, EMG latencies were derived for each muscle.

## 2.2. Results

Fig. 2 shows the rectified and averaged EMGs of 10 trials from the start of the response signal in each of the three muscles in the N (Fig. 2(A)) and the PNF position (Fig. 2(B)), respectively. As expected, the EMG discharge order differed between the two positions. In the PNF position the EMG discharge consistently started in the muscle nearest to the wrist joint (B), whereas this was not the case in the N position (arrows in Fig. 2). Furthermore, before the movements started, the prime mover (B) clearly showed weak background muscle activity in the PNF position (filled triangle in Fig. 2(B)) but not in the N position (open triangle in Fig. 2(A)). This suggests that

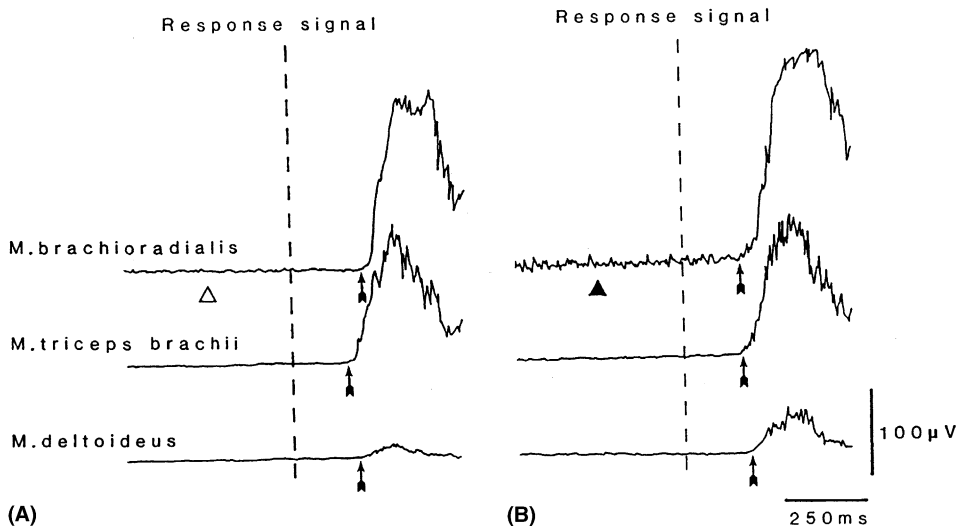


Fig. 2. Rectified and averaged (ten trials) EMGs of the three muscles in the N (panel A) and PNF (panel B) position. EMG discharge order of three muscles (arrows) was influenced by changes in limb position. In the PNF position, muscle discharges occurred in the order brachioradialis (B), triceps brachii (T) and deltoideus (D). In addition, background EMG activity of the brachioradialis was markedly higher in the PNF position (filled triangle) than in the N position (open triangle).

excitability of this muscle increased in the PNF position, although this increase was not observed in any single reaction trial because the excitability changes may have consisted of subthreshold depolarization.

To examine these phenomena quantitatively, we calculated the frequency of the EMG discharge order of the three muscles in the N and PNF position. Fig. 3(A) shows a typical distribution of an EMG discharge pattern as observed in one of the subjects (A.N). It indicates that changes in muscle discharge order are greater the nearer the muscle is located to the wrist joint. As can be appreciated from

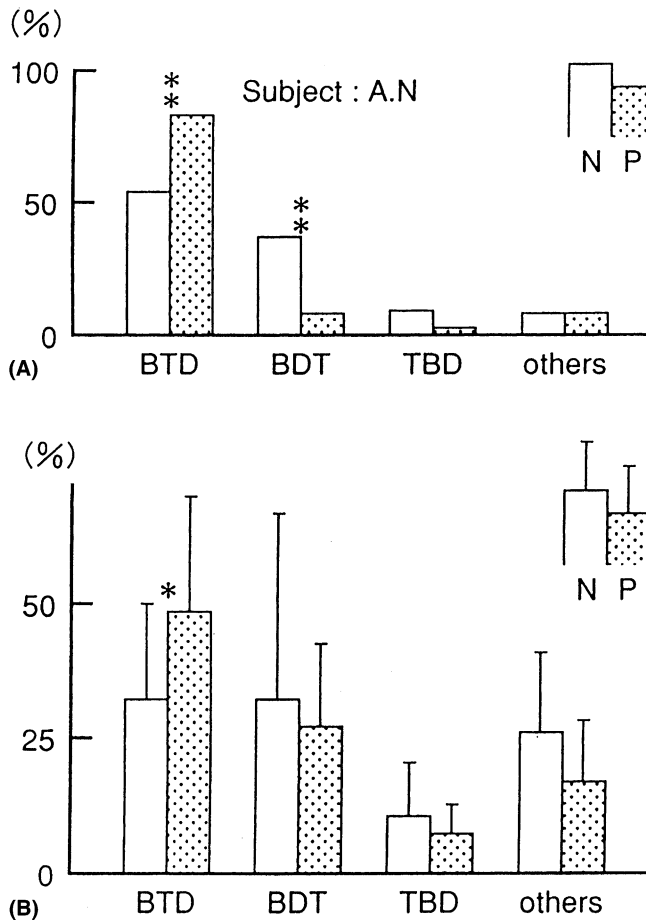


Fig. 3. Comparison of the frequency of muscle discharge order of the three muscles between the N and PNF position in subject A.N. For example, “BTD” indicates that muscle discharge occurred in the order B, T, and D.B. Averages and standard deviations of each muscle discharge order for all subjects tested ( $n = 7$ ). Results show that the frequency of occurrence of a muscle discharge order beginning with the muscle closest to the movement joint is higher in the PNF position than in the N position. \*  $p < 0.05$ , \*\*  $p < 0.01$ .

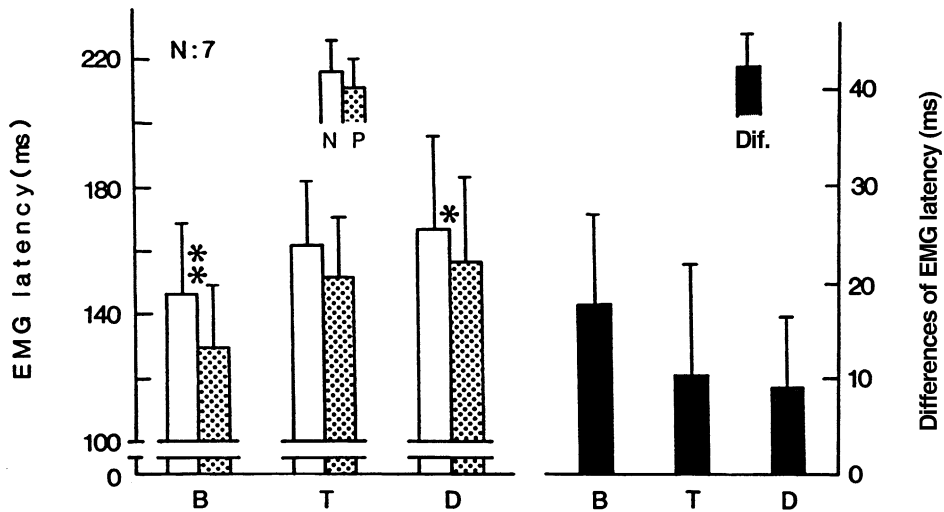


Fig. 4. EMG-RTs of the three muscles in the N and PNF position (open and dotted columns at left, respectively), and the differences in the EMG-RT between the two positions (filled columns at right). \* $p < 0.05$ , \*\*  $p < 0.01$ .

Fig. 3(A), the order BTD occurred significantly more often in the PNF position than in the N position ( $\chi^2 = 7.4$ ,  $df = 1$ ,  $p < 0.01$ ), while the converse was true for the order BDT ( $\chi^2 = 16.9$ ,  $df = 1$ ,  $p < 0.01$ ). Fig. 3(B) shows that the significant effect for the occurrence of the order BTD across the two positions was preserved in a paired  $t$ -test for all subjects ( $t = 3.26$ ,  $df = 6$ ,  $p < 0.05$ ).

To examine why the discharge combination of the B, T and D muscles differed for the two limb positions (N vs PNF position), the EMG-RTs were calculated. Fig. 4 shows the interindividual means and standard deviations ( $n = 7$ ) of the EMG-RT for each muscle in each position (left panel), as well as the averaged differences in the EMG-RT between the two positions (right panel). The EMG-RTs were significantly shorter in the PNF position than in the N position in all three muscles (B:  $t = 4.44$ ,  $p < 0.01$ ; T:  $t = 2.11$ ,  $p < 0.10$ ; D:  $t = 3.10$ ,  $p < 0.05$ ,  $df = 6$ ). Furthermore, the reduction in EMG-RT was greatest in B ( $F = 5.11$ ,  $df = 2/18$ ,  $p < 0.05$ ).

### 2.3. Discussion

To replicate previous findings that the initiation of voluntary movement is dependent on initial limb position (Furubayashi & Kasai, 1990; Nakamura et al., 1979; Nara & Kasai, 1991; Taniguchi et al., 1984, 1980), the subjects in Experiment 1 were required to extend their wrist in two positions (N and PNF). The EMG-RTs of the three muscles involved in the wrist extension were shorter in the PNF than in the N

position. The reduction in EMG-RT across the two positions was largest in the muscle closest to the wrist joint (B) and weakest in the most distant muscle (D). Therefore, the EMG discharge order BTD occurred most frequently.

As regards the neural mechanisms underlying these effects, it is well known that changes in limb position result automatically in changes in the activation thresholds of relevant muscles due to stretch reflex mechanisms (Etnyre & Abraham, 1986; Guissard et al., 1988; Kasai, 1981; Mark et al., 1968; Robinson et al., 1982; Romano & Schieppati, 1987; Smith et al., 1974; Weiss et al., 1986). In this manner, EMG activation patterns can be modulated.

It is further known that spinal responses increase in proportion to the level of activity within the motoneuron pool, a mechanism that has been referred to as automatic gain compensation (e.g., Kernell & Hultborn, 1990). Since the automatic gain control of corticospinal input in hand muscles is described by the linear relationship between the level of pre-existing EMG activity and the sizes of their responses (Bennet & Lemon, 1994), it is conceivable that different pre-existing excitation levels induced by the PNF position lead to different degrees of reduction in EMG-RT.

Although our observations suggest that assuming a PNF position alters the baseline muscle excitability state at a spinal level (filled triangle in Fig. 2), the present results cannot be explained by spinal mechanisms alone because changes in limb position influence several motoneuron pools simultaneously as described in the preceding. Rather, the present results indicate that the effects of limb position change not only occur at the spinal level but also at supraspinal levels, including the cortex. To examine the occurrence of changes in excitability at the cortical level, we subsequently conducted a similar experiment using a TMS technique.

### **3. Experiment 2**

In particular, by means of TMS we activated the same muscles as studied in Experiment 1, and recorded their MEPs while the subject assumed the same limb positions as in Experiment 1. Both electrical (Merton & Morton, 1980) and TMS (Barker et al., 1985) produce complex descending corticospinal volleys which usually contain a direct component (via corticospinal neurons) and an indirect trans-synaptic component. Specifically, the magnetic stimulation activates the output trans-synaptically (producing indirect, or I-waves), which would account for its longer latency of response in upper limb muscles than with electric stimulation (cf. Rothwell, Thompson, Day, Boyd, & Marsden, 1991). As suggested in the context of Experiment 1, the effects of PNF position probably occur at a spinal level as well as at supraspinal levels, including the cortex. In particular, changes in cortical excitability can affect both the evoked corticospinal volleys and the electromyographic responses which are triggered by these volleys (MEPs). We therefore used TMS to investigate the

effects of the N and PNF position on cortical excitability by comparing the amplitudes and latencies of the MEPs.

### 3.1. Methods

#### 3.1.1. Subjects

The subjects were four males (38–43 years old) without neural impairments. The subjects gave informed consent in accordance with local institutional guidelines and the ethical standards formulated in the 1964 Declaration of Helsinki.

#### 3.1.2. Procedure

MEPs were recorded with an MES-10 magnetic stimulation apparatus manufactured by Cadwell (London, UK). Based on the recommendations of the International Federation of Clinical Neurophysiology (IFCN) committee (see Rossini et al., 1994), a single coil of 8 cm diameter was used to carefully search the two muscles of the upper limb for the site at which the MEP occurred with the lowest stimulus intensity. The current pulse through the coil was largely monophasic and had a maximum duration of less than 1 millisecond. This produced a magnetic field with a maximum strength of 1.5 T at the center of the coil. The coil was applied in such a way that the left hemisphere was stimulated. The position on the left scalp from which TMS produced the greatest MEPs of the right hand was determined. The stimulation was always applied at this position, which was marked for this purpose. The TMS was increased in 5% steps in order to determine the threshold intensity for the target muscle. The m. deltoideus (D) was excluded because its background EMG could not be eliminated in the PNF position. The MEPs of the relaxed m. brachioradialis (B) and m. triceps brachii (T) were recorded in both the N and PNF positions. The threshold was defined as the intensity of stimulation required to produce EMG response of 50  $\mu$ V in 50% of the trials. A magnetic stimulation of 1.1–1.3 times the threshold intensity was used as test intensity. There were five measurement blocks. Within each block, MEPs were recorded three times for each muscle (B and T) in both the N and PNF positions. The amplitude and latency of the so-obtained 15 MEP records for each muscle were determined following the procedure explained before. Subsequently, means and standard deviations were calculated. The EMG recording system and data analysis were the same as in Experiment 1.

### 3.2. Results

Representative examples of the actual MEP records of one block, presented in Fig. 5(A), clearly show that the MEP amplitude in the PNF position was substantially larger than in the N position. Fig. 5(B) shows the MEP amplitudes of the B and T muscles for the two positions averaged across all subjects ( $n = 4$ ). The difference between the two positions was significant for both muscles (B:  $t = 3.79$ ,  $p < 0.05$ ; T:  $t = 5.81$ ,  $p < 0.05$ ,  $df = 3$ ).

In addition, the interindividual mean MEP latencies were significantly shorter in the PNF than in the N position for both the B muscle (PNF: 15.5, S.D. = 0.4 vs N:



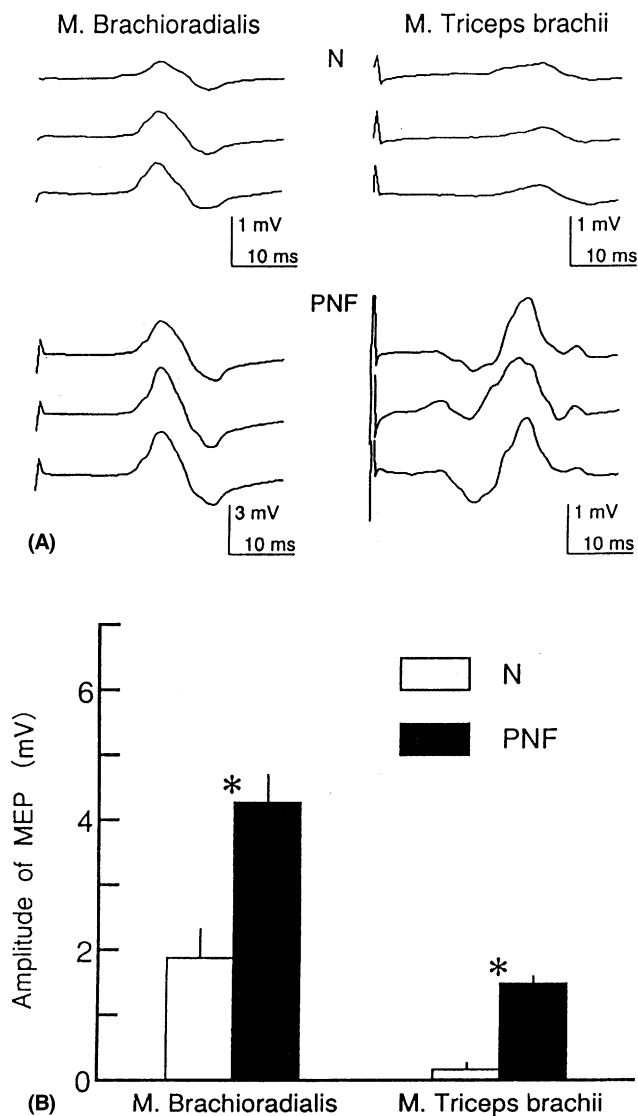


Fig. 5. Representative examples of actual MEP records of m. brachioradialis and m. triceps brachii in the N and PNF position. Three EMG traces of one block are shown for each muscle and each condition. In both muscles MEP amplitudes were greater in the PNF than in the N position. (B) Comparison of MEP amplitude values between the N (open columns) and PNF (filled columns) position in both muscles for all four subjects tested. The differences in amplitude were statistically significant. \*  $p < 0.05$ .

18.0, S.D.=0.2;  $p < 0.05$ ) and the T muscle (PNF: 11.3, S.D.=0.6 vs N: 15.7, S.D.=0.4;  $p < 0.01$ ).

### 3.3. Discussion

As expected, we found that the MEP amplitude was larger and its latency shorter in the PNF than in the N position. We assume that these results are due to the fact that the amount of sensory input coming from the periphery was greater in the PNF position than in the N position, which induced changes in the excitability of the pyramidal tract, the final motor pathway (Benecke, Meyer, Gohmann, & Conrad, 1988; Day et al., 1987; Hess, Mills, & Murry, 1987; Kasai, 1989, 1993; Rothwell et al., 1987). Many details of the neurophysiological mechanisms involved in transforming sensory inputs from the periphery to motor outputs are still unknown (Gandevia & Rothwell, 1987; Kasai, Hayes, Wolfe, & Allatt, 1992; Kasai, Kawanishi, & Yahagi, 1996; Kasai, Toyoda, & Yahagi, 1997; Yahagi & Kasa, 1998; Yahagi, Shimura, & Kasai, 1996). Therefore, one can only speculate about the causes of the advantage of the PNF position. One possibility, discussed by Deletis, Dimitrijevic, & Sherwood (1987) and Kasai et al. (1992), is that in the PNF position sensory inputs from the periphery lead to stronger excitation of the cortical area, leading to variations in the thresholds of a number of motoneurons, which is reflected in the MEPs. Another possibility is that the PNF position alters the baseline excitability of muscle in spite of this not being observed in any single reaction trial, because the changes in excitability are subthreshold. Taken together, the effects of the PNF position influence the cortical and the spinal activation prior to voluntary movement and consequently lead to a reduction in EMG-RT and excitability changes reflected in the MEPs.

Our results and conclusions are consistent with those of Hummelsheim and colleagues (Hauptmann & Hummelsheim, 1996; Hauptmann, Skrotzki, & Hummelsheim, 1997; Hummelsheim, Hauptmann, & Neuman, 1995), who also studied the effects of PNF positions of the upper limbs on MEPs. Although the focus of their analysis differed from ours, they also concluded that sensory information from the periphery induced by PNF position facilitates MEPs while reducing latency. Like us, they provided electrophysiological data which may help to clarify the neurophysiological mechanisms underlying the PNF technique, and thus in the long run, may help to improve rehabilitation practice.

### 4. General conclusion

In sum, on the basis of the results of Experiments 1 and 2, we conclude the following:

1. PNF position improves movement efficiency of the joint by inducing changes in the sequence in which the muscles are activated.
2. The reduction in EMG-RT due to adopting an PNF position increases with the proximity of the muscle to the movement joint.
3. The increase in MEP amplitude and decrease in MEP latency observed in the PNF position also correspond to the proximity of the muscle to the movement joint.

4. In all likelihood, these experimental effects of PNF are mediated by changes in excitation level of the cortical motor area and the corresponding motoneurons.

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