H-reflexes are smaller in dancers from The Royal Danish Ballet than in well-trained athletes

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Summary. The size of the maximal *H*-reflex (H_{max}) was measured at rest and expressed as a percentage of the maximal *M*-response (M_{max}) in 17 untrained subjects, 27 moderately trained subjects, 19 well-trained subjects and 7 dancers from the Royal Danish Ballet. The H_{max}/M_{max} was significantly larger in the moderately and well-trained subjects than in the untrained subjects but smaller in the ballet dancers. It is therefore suggested that both the amount and the type of habitual activity may influence the excitability of spinal reflexes.

Key words: Ballet dancers – *H*-reflexes – Ia afferents – Reciprocal inhibition – Reflex pathways – Spinal cord – Training

Introduction

The soleus *H*-reflex has been shown to be a monosynaptic reflex elicited by electrical stimulation of Ia afferents in the posterior tibial nerve (Hoffmann 1910, 1918; Magladery and McDougal 1950). The size of the reflex is thus a measure of the central gain of the monosynaptic stretch reflex and it is determined by:
1. The transmission across the synapses of the Ia afferents and
2. The excitability of the motoneuronal pool.
   Changes in the size of the reflex during various voluntary tasks or following different conditioning stimuli have consequently been used during the last 15 years to study *short-term* changes in these two parameters (Schieppati 1987).
   It is well-known that the size of the maximnal obtainable reflex at rest differs considerably among normal subjects (Taborikova and Sax 1968; Schieppati 1987).

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This variability could be caused by a genetically determined variation but several studies in recent years have suggested that a considerable *long-term* adaptation to the habitual physical activity of the subject may also take place. The *H*-reflex has thus been reported to be smaller in elite volleyball players and sprinters than in untrained control subjects (Rochcongar et al. 1979; Casabona et al. 1990). In monkeys, it has also been demonstrated that operant conditioning can induced a long lasting adaptation of the *H*-reflex size (Wolpaw and Lee 1989; Wolpaw and Carp 1990).

It was the purpose of the present study to provide further evidence supporting the existence of *long-term* changes in the reflex excitability.

Methods

Subjects. The experiments were performed on 70 healthy subjects aged 18–64 years. All subjects gave informed consent to the experimental procedure, which was approved by the local Ethics Committee. At the beginning of each experiment the subjects were questioned about any physical activity undertaken within the previous year but they were not given any information about the purpose of the experiment until after it had taken place. They were divided into four different groups:
1. A group of 17 untrained subjects (sedentary), who did not perform any kind of sport or exercise
2. A group of 27 subjects who exercised regularly but did not perform any kind of sport
3. A group of 19 subjects who participated in different kinds of sport
4. A group of 7 subjects from The Royal Danish Ballet.
   The subjects in group 2 exercised from 1 to 10 h a week, the subjects in group 3 from 15 to 20 h a week and the ballet-dancers for more than 25 h a week. The most common types of exercise in group 2 were jogging (90%), swimming (75%) and cycling (90%). Some subjects practised aerobics or other kinds of gymnastics. A few subjects attended a fitness-centre. All of the subjects in group 3 also performed one or two of the above-mentioned types of exercise in addition to their sport and several of them performed more than one sport. There were 7 subjects who were volleyball-players, 5 who were football-players, 5 who were handball-players, 2 who were basketball-players and 1 who was a marathon-runner. None of the ballet dancers performed any other kind
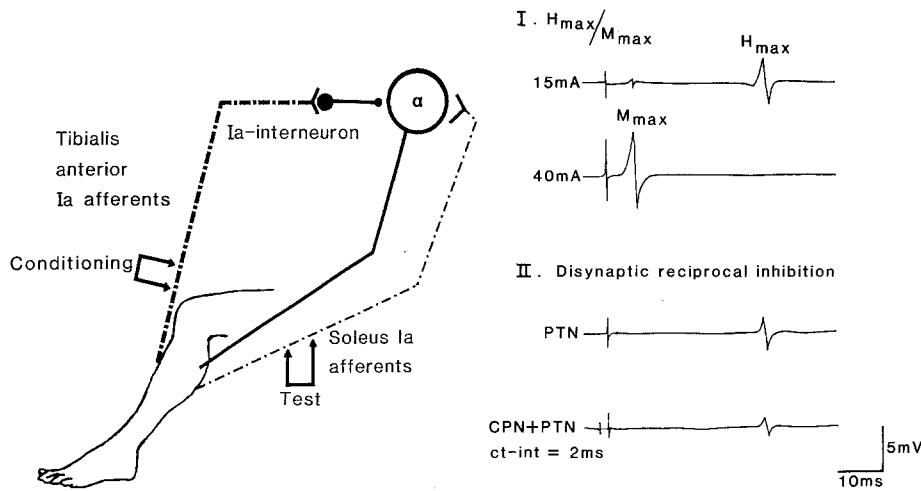
Fig. 1 Diagram of the experimental setup. The soleus H-reflex was elicited by a stimulation of the posterior tibial nerve (*PTN*) in the fossa poplitea. The maximal obtainable H-reflex (H_{max}) was expressed as a percentage of the maximal direct M-response (M_{max}) following supramaximal stimulation of the nerve (**I**). The disynaptic reciprocal inhibition (**II**) was obtained by conditioning the soleus H-reflex using a preceding (delay 2–3 ms) stimulation of the common peroneal nerve (*CPN*). ct, conditioning test; int., interval

of exercise. The numbers of men and women were about equal in groups 1–3. There were 2 male ballet dancers. There were no significant age differences amoung the four groups.

Experimental procedure. All measurements were made while the subjects were sitting at rest. They were seated in a reclining armchair with the examined left leg flexed at the hip (120°), the knee flexed to 160° and the ankle at 110° plantarflexion. The foot was attached to a footplate.

A diagram of the experimental setup is given in Fig. 1. Surface electrodes were used for both stimulation and recording. The soleus H-reflex was evoked by stimulating the tibial nerve in the fossa poplitea through a monopolar stimulating electrode (1-ms rectangular pulses). The reflex response was measured as the area below the full-wave rectified H-reflex recorded by bipolar nonpolarizable disc electrodes (1 cm² recording area; 2 cm between poles) placed over the soleus muscle. The size of the maximal motor response (M_{max}) was measured at the beginning of the experiment and the size of the H-reflex was subsequently expressed as a percentage of this response. The maximal obtainable H-reflex (H_{max}) was measured as the largest of ten reflexes obtained in three independent trials. A stimulus interval of 4 s was used.

The disynaptic reciprocal inhibition was obtained by conditioning the soleus H-reflex by a preceding stimulation of the common peroneal nerve. This stimulation activated Ia afferents which project to Ia inhibitory interneurons, which produced reciprocal inhibition of the soleus motoneuronal pool. The conditioning stimulus (rectangular 1 ms pulse) was given at the level of the head of the fibula to the branch of the peroneal nerve supplying the tibialis anterior muscle. The stimulating electrode was a bipolar surface electrode. The conditioning stimulus strength was expressed in multiples of the motor threshold (Th_{motor}) in the tibialis anterior muscle determined by the appearance of an M-response in the electromyogram recorded by a surface electrode placed over the tibialis anterior muscle. A stimulus strength of $1.0 \times Th_{motor}$ was used in the experiments. A control (without conditioning stimulation of the comon peroneal nerve) reflex size of 15%–25% (on the ascending part of the H-reflex recruitment curve) was used in all experiments. A time course of the effect of the conditioning stimulus on the soleus H-reflex at rest was obtained at the beginning of each experiment. The maximal amount of reciprocal inhibition in the subject was measured as the average inhibition at the optimal conditioning-test interval (the one with which the largest depression of the H-reflex was seen; usually 2–3 ms). This average was obtained from at least three independent series. Each series consisted of at least 20 reflex measurements (control and conditioned). The stimuli were given every 4 s in a randomized sequence of control and conditioned test stimuli. The inhibition was calculated from the difference between conditioned and control reflexes and expressed as a percentage of the control reflex size.

Differences in the size of H_{max}/M_{max} and the disynaptic reciprocal inhibition among the four groups were tested using an unpaired Student's t-test.

Results

Intra-individual variability

The measurements of H_{max} and the disynaptic reciprocal inhibition were very reproducible in the same subject from experiment to experiment. This is demonstrated in Fig. 2, which gives measurements from the same subject for a period of 3 years. As can be seen, H_{max}/M_{max} varied by no more than 5% and the disynaptic reciprocal inhibition by no more than 10% during the period. The
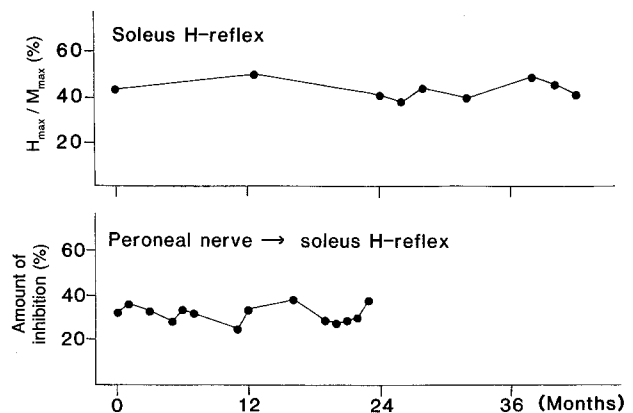

Fig. 2 The size of H_{max}/M_{max} (*upper graph*) and the disynaptic reciprocal inhibition (*lower graph*) in the same subject measured in several different experiments throughout a 2–3½ year period. The amount of reciprocal inhibition was measured as the conditioning test interval at which the largest amount of inhibition was seen for the subject in each experiment (conditioning test interval of 2 or 2.5 ms). The conditioning stimulation strength was $1.0 \times$ motor threshold. In the *upper graph,* the *ordinate* is the size of H_{max} as a percentage of M_{max}. In the *lower graph,* the *ordinate* is the difference between the conditioned reflex and the control reflex expressed as a percentage of the control reflex size. The *abscissa* is the time in months from the first to the last experiment. Each point represents 20–40 measurements. Definitions as in Fig. 1

subject exercised regularly about 2 h a week (jogging and cycling) during the whole period. A similar reproducibility was found in 5 other subjects who were tested several times during the 3-year period.

Activity related differences in H_{max} and disynaptic reciprocal inhibition

The size of both H_{max}/M_{max} and disynaptic reciprocal inhibition was found to be larger in the trained subjects than in the untrained subjects as can be seen from Figs. 3 and 4. The average size of H_{max}/M_{max} was 45.5% (range 15%–90%) for the 17 sedentary subjects in group 1, compared to 61.5% (range 15%–90%) for the 27 subjects who exercised regularly and 71.5% (range 29%–82%) for the 19 subjects who, in addition, participated in some kind of sport. These differences were found to be statistically significant (group 1 vs group 2: $P<0.01$; group 1 vs group 3: $P<0.001$; group 2 vs group 3: $P<0.05$). The disynaptic reciprocal inhibition was likewise only 11.9% (range 0%–25%) on average in the untrained group compared to 17.9% (range 0%–35%) and 21% (range 10%–35%) for the two trained groups, respectively. The amount of inhibition in the trained subjects was thus significantly larger than in the sedentary subjects ($P<0.05$). It was also investigated as to whether the stimulation of the common peroneal nerve evoked a reflex in the tibialis anterior muscle. Such a reflex response was only seen in the moderately and well-trained subjects, thus demonstrating that the tibialis anterior reflex excitability was also larger in the trained subjects compared to the sedentary subjects.

Task-related differences in the size of H_{max} and disynaptic reciprocal inhibition

The higher level of activity thus appeared to be accompanied by an increase in the size of H_{max} and disynaptic reciprocal inhibition. That the level of activity as such was not the only determinant was, however, shown by the measurements made on the subjects from The Royal Danish Ballet. The ballet dancers exercised much more strennously than any of the other subjects (more than 25 h a week) but nevertheless all had very small reflexes (average 35%, range 10%–60%) and hardly any disynaptic reciprocal inhibition (average 4%, range 0%–10%). The size of the reflex in the ballet dancers was thus significantly smaller than the other trained subjects ($P<0.01$ and $P<0.001$, respectively) but not significantly smaller than in the untrained subjects. A reflex response in the tibialis anterior muscle was not observed in any of the dancers.

The ballet dancers were unique, since they performed no other type of exercise. All the other subjects performed two or more diferent types of sport or exercise (football and jogging, volleyball and swimming, swimming and jogging, etc.). This part of our material was thus not optimal for elucidating whether the particular sport or exercise that the subject performed had any in-
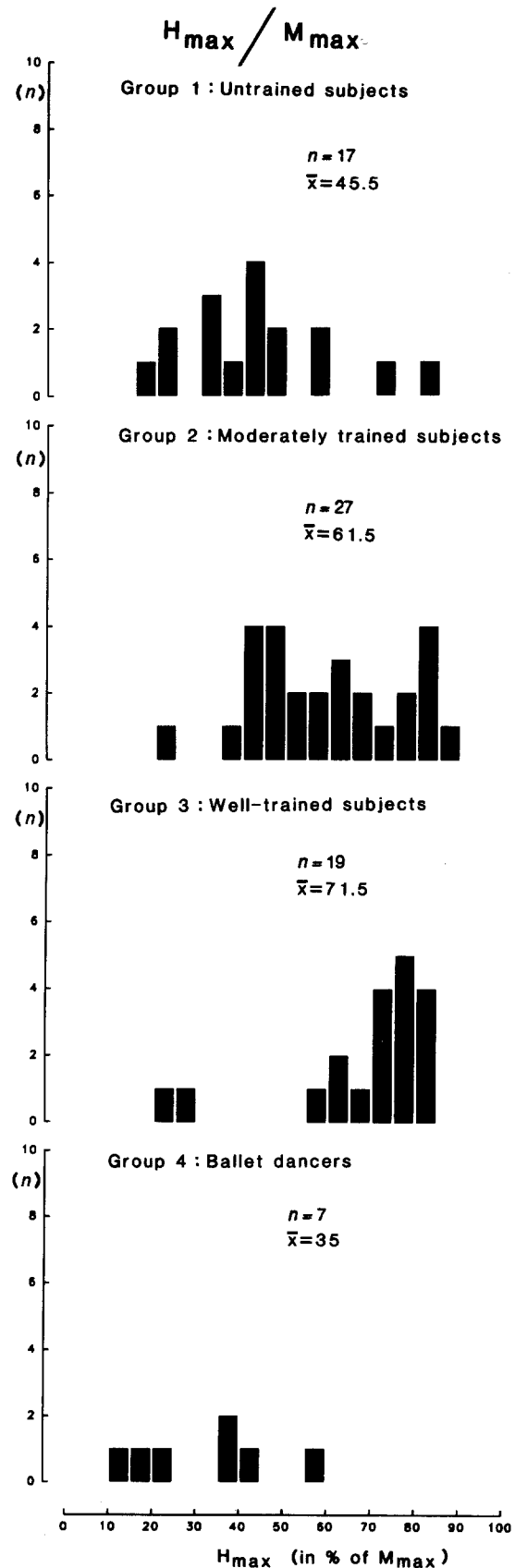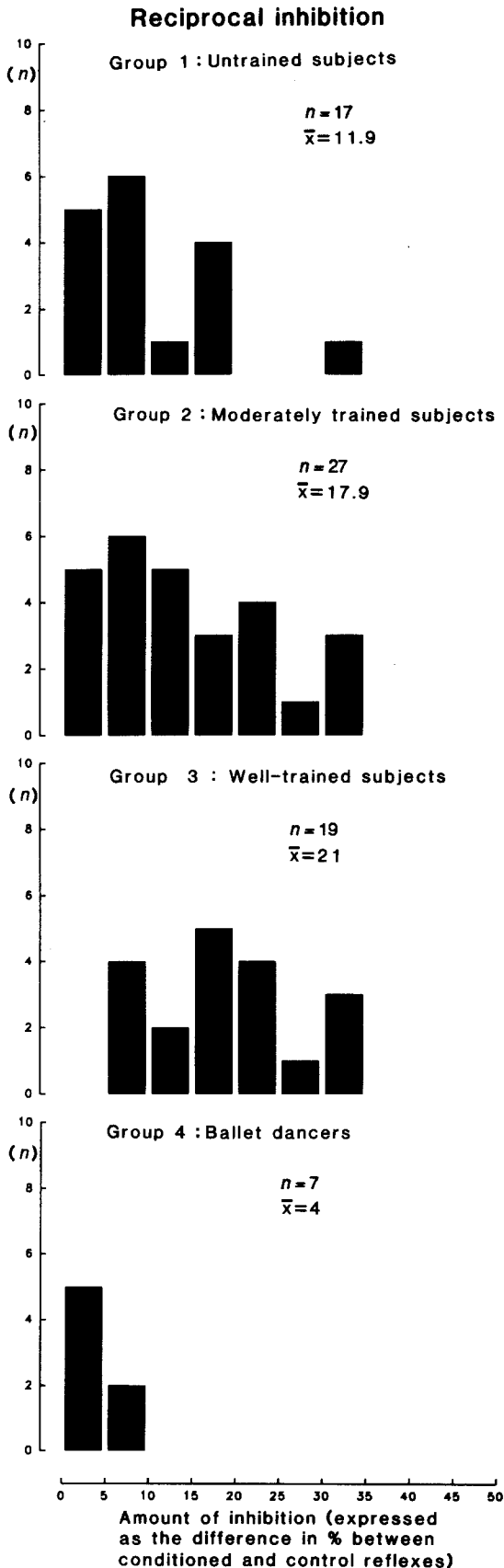

Fig. 3 The distribution of the size of H_{max}/M_{max} in the subjects from the four different groups. The *ordinate* is the number of subjects (N) in whom a reflex of a given size (*abscissa*) was measured. The H_{max}/M_{max} were grouped in steps of 5%. Definitions as in Fig. 1

Reciprocal inhibition

Group 1 : Untrained subjects

n = 17
x̄ = 11.9

Group 2 : Moderately trained subjects

n = 27
x̄ = 17.9

Group 3 : Well-trained subjects

n = 19
x̄ = 21

Group 4 : Ballet dancers

n = 7
x̄ = 4

Amount of inhibition (expressed as the difference in % between conditioned and control reflexes)

fluence on the reflex size. We did, however, observe that H_{max}/M_{max} was smaller in the football players than in the other well-trained subjects (57% compared to 72.4% in the volleyball players, 72.8% in the handball players and 71% in the basketball players). Because of the small sample this difference was not statistically different.

Discussion

The observation that H_{max}/M_{max} and disynaptic reciprocal inhibition were larger in trained athletes than in sedentary subjects would suggest that the level of activity may have influenced the excitability of simple spinal pathways. This possibility has already been suggested by Eccles (1953), who, in observing that the size of monosynaptic excitatory postsynaptic potentials in motoneurons may be increased by long-term stimulation of the dorsal roots, stated that "usage leads to increased functional efficiency of synapses and disuse to defective function". In support of this it has been a common finding that the achilles tendon reflex (T-reflex) is more often absent in elderly subjects than in younger ones (Milne and Williamson 1972; Bathia and Irvine 1973) and that H_{max}/M_{max} declines with age (Sabbahi and Sedgwick 1982). That this may be due to the smaller activity level of the older subjects has been suggested by DeVries et al. (1985) who did not observe any difference in H_{max}/M_{max} when matching the activity levels of a young and an old age group.

The effect of physical activity may, however, be opposed by other mechanisms. This is suggested in the present study by the finding that both H_{max}/M_{max} and the disynaptic reciprocal inhibition were smaller in the very well-trained ballet dancers than in the well-trained athletes. Our observation thus confirm a previous study by Goode and Van Hoven (1982), in which they have observed that classical ballet dancers lack achilles and patellar tendon reflexes. In previous studies it has also been reported that H_{max}/M_{max} is smaller in anaerobically (sprinters) than in aerobically (long-distance runners) trained athletes (Rochcongar et al. 1979) and in volleyball players in relation to other athletes (Casabona et al. 1990). Finally, Rochcongar et al. (1979) have observed that H_{max}/M_{max} is significantly larger in aerobically trained swimmers (H_{max}/M_{max}, 75%) than in control subjects (H_{max}/M_{max}, 50%). All the well-trained athletes in the present study were predominantly aerobically

Fig. 4 The distribution of the amount of disynaptic inhibition in the subjects from the four different groups. The amount of inhibition was measured at the conditioning test interval at which the largest amount of inhibition was seen in each subject (2–3.5 ms). The stimulation strength was 1.0 × motor threshold in all cases. The amount of inhibition was calculated as the difference between conditioned and control reflexes, expressed as a percentage of the control reflex size and presented in steps of 5%

trained, including the volleyball-players, whose daily exercise was for the most part jogging. Thus, our observation of large reflexes in these subjects does not contradict the observation of Casabona et al. (1990) and indeed may confirm the observations by Rochcongar et al. (1979).

As mentioned in the Introduction the observed differences in the H-reflex size for the different subjects may be explained by differences in either:

1. The excitability of the motoneuronal pool or
2. In the transmission across the Ia synapses.

In the studies by Rochcongar et al. (1979) and Casabona et al. (1990), it was suggested that the small size of the reflex in the anaerobically trained subjects could be explained by a larger fraction of type II muscle fibres in the muscles of these subjects. It is well-known that small type S (slow) motoneurons (supplying type I muscle fibres) are more easily excited by a volley in Ia afferents than the larger type F (fast) motoneurons (supplying type II muscle fibres) (Hennemann et al. 1965, 1974; Buchtal and Schmalbruch 1976; Burke 1981). A change in motor unit properties in the pool towards type F would consequently result in a lower excitability of the motoneuronal pool and thus in smaller reflexes. This interpretation is, however, in conflict with the fact that the soleus muscle consists dominantly of type I muscle fibres (more than 90%) and it is consequently difficult to explain the differences in the reflex size among the subjects in the present study by a larger fraction of type II fibres. If the differences in the reflex size were caused by differences in motoneuron excitability, these differences must necessarily have been located within the limits of each motor unit type.

In our opinion it is more likely that the differences in the reflex size were caused by differences in the transmission across the synapses of the Ia afferents. One of the mechanisms, that has been shown to modulate this transmission, is presynaptic inhibition [probably by GABA-ergic synpatic connections to Ia afferent terminals (Eccles et al. 1962; Schmidt 1971)]. A pronounced presynaptic inhibition of Ia afferents would cause both small reflexes and small disynaptic reciprocal inhibition as seen in the ballet dancers in the present study and of the H-reflex in the volleyball players and sprinters in the studies by Rochcongar et al. (1979) and Casabona et al. (1990). In this context it is of particular interest that the ballet dancers have to perform a co-contraction of antagonistic muscles to maintain balance during the classical ballet postures and that a pronounced *increase* of presynaptic inhibition and *decrease* of disynaptic reciprocal inhibition has ben reported during such contractions (Nielsen and Kagamihara 1992, and in press). The classical form of presynaptic inhibition is most likely used for a moment-to-moment control of the Ia transmission to motoneurons (and interneurons) in different types of motor tasks (Hultborn et al. 1987). There are also long-term changes of synaptic transmission residing at the presynaptic level – perhaps these changes are initiated by a frequent increase or decrease in presynaptic inhibition. Experiments in the monkey, would indeed suggest that changes in presynaptic inhibition have been

the cause of the long-term changes in the size of the H-reflex following operant conditioning (Wolpaw and Lee 1989; Wolpaw and Carp 1990). Similarly, Kandell and co-workers have convincingly demonstrated that presynaptic mechanisms, including presynaptic inhibition, are the cause of the long-term adaptation of the monosynaptic gill-withdrawal reflex in Aplysia (Small et al. 1989). We would, therefore, suggest that the daily performance of co-contraction with a short-term increase of presynaptic inhibition may finally result in an enduring long-term reduction of synaptic transmission, thus explaining the small H-reflexes and the small amount of disynaptic reciprocal inhibition in the ballet dancers.

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