VIBRATION TRAINING

Mechanisms and possible mechanisms relating to structural adaptations and acute effects

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SWEELINCKPLEIN 45-46 • 2517 GP DEN HAAG • NEDERLAND • TEL 070 346 1234 • FAX 070 345 5474
E-MAIL ADRIEVANDIEMEN@CS.COM • HTTP://WWW.ADMOTION.NL
INGESCHREVEN BIJ DE K.V..K. TE LEIDEN NR. 280 71958 • RABOBANK LEIDEN 3355.88.034

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1. Introduction

In recent years, vibration training has received attention from science and in practice as an interesting means of achieving progress in terms of strength and speed within a short time. In addition, it has been shown that vibration training is also capable of increasing flexibility and bone density. The studies involving vibration are not unambiguous, however, which also applies to the methods used in the various studies. Where vibration frequency, amplitude and acceleration alone are concerned, practically no study is the same.

The objective of this literature study is to bring clarity to the scientific results on the effects of vibration. These results are compared with current knowledge of the motor system. This method will expose the underlying mechanisms of the effects found, or the lack of these. There are still large gaps in the knowledge of the human motor system, which means that not all the mechanisms put forward in this report can avoid being hypothetical in nature. This deficiency in scientific knowledge emphasizes the importance of knowledge of vibration training gained in practice with day-to-day training. Science by no means has all the answers to questions based on practical experience and can neither confirm nor deny some practical findings. It is of major importance, therefore, to listen to the experiences of athletes and patients in rehabilitation, and to document these experiences in practice.

The structure of this report is as follows. Chapter 2 provides a brief summary of present knowledge in the field of the motor system in general and spinal reflexes in particular. The latter are of particular importance in vibration training, which is presumed to have the greatest effect on this part of the motor system. Chapter 3 is a short introduction to the development of vibration training. The origins of vibration training are considered, its initial applications and recent developments. This is followed in chapter 4 by an overview of the potential of vibration training. Vibration training engages at the level of spinal reflexes and these reflexes have a great potential for increasing their efficiency.

Chapter 5 is the most important section of this report. This chapter consists of an extensive review of the studies which have specifically researched the effects of vibration on force, power and flexibility, among other things. The effects on force and power are divided into acute effects and structural adaptations, because these two effects are produced by different mechanisms.

Finally, chapter 6 contains a discussion of these results and their practical implications, while recommendations are also made for further research.

drs. A. van Diemen Phd. exertions physiologist.

2. Relevant Neurophysiology

2.1 The muscle spindle

The muscle spindle is located in the muscle. It provides the central nervous system with information about the momentary length and the speed of change in length of the host muscle. Figure 1 shows a diagram of the organization of the muscle spindle. The muscle spindle consists of a nuclear bag fiber and a nuclear chain fiber. II secondary afferents come from the nuclear chain fiber and Ia primary afferents from nuclear bag fiber and nuclear chain fiber.

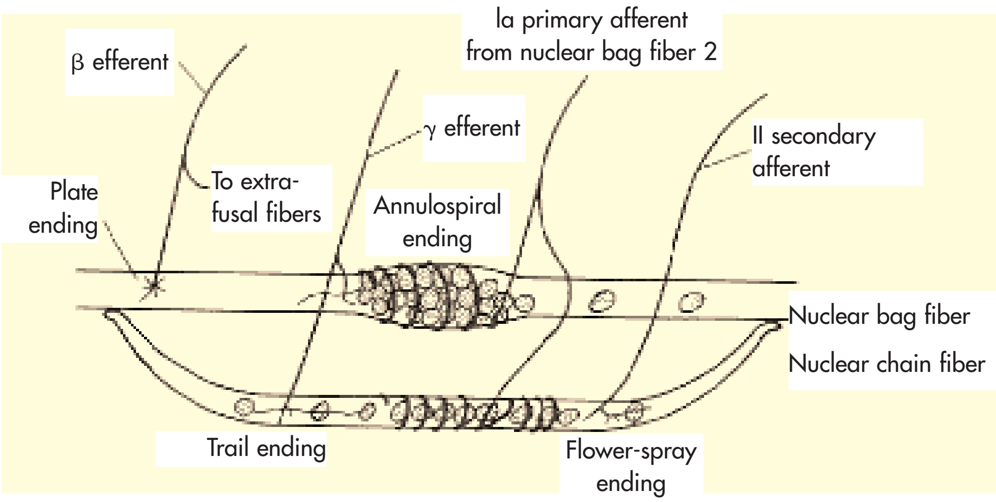

Figure 1: A diagram of the muscle spindle. From: Review of Medical Physiology. (1995) Ganong WF)

The efferent fibers of the muscle spindle are the γ efferents, which can be divided into γ d efferents, (which innervate the nuclear bag fiber) and γ s efferents (which innervate the nuclear chain fiber). The afferent fibers detect stretch in the equatorial part of the muscle spindle, the part that the afferent fibers are wound around. The γ fibers innervate the intrafusal fibers, which is to say the endings of the muscle spindle. When these contract, the equatorial part is stretched and the Ia afferents start firing impulses. In a resting muscle, the muscle spindle constantly discharges signals through Ia afferents. It is in a permanently stretched state, as a result of the activity of γ efferents, which enables the muscle to detect both stretch and contraction. Furthermore, the muscle spindle can now also detect a minor stretch, which would not be possible without the basic activity of γ efferents. The response of the muscle spindle to stretch in the muscles is illustrated in figure 2. The outermost muscle fibers are what are known as the extrafusal fibers, or the muscle fibers that lie around the muscle spindle.

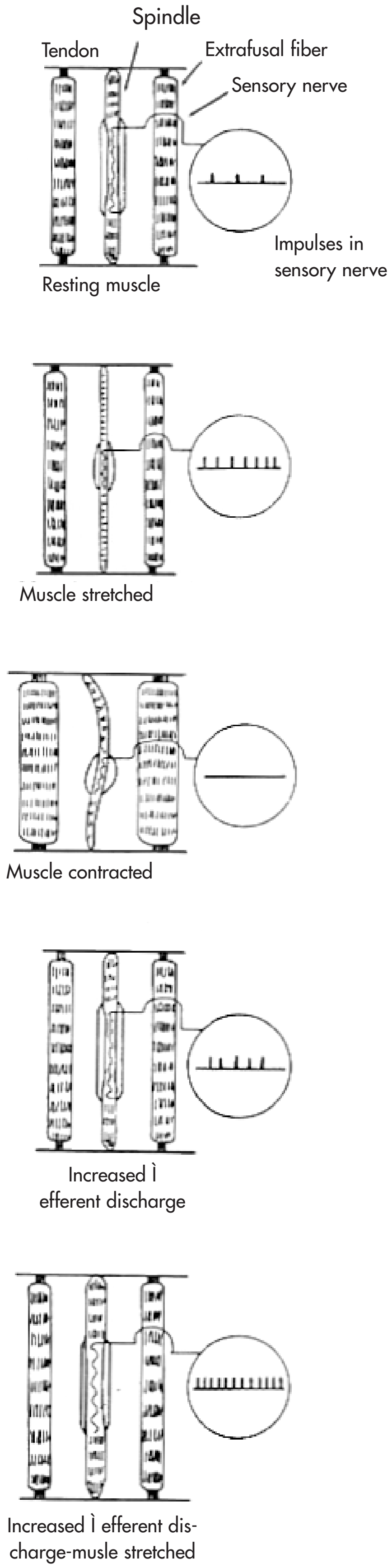

Figure 2: Response of the muscle spindle in different circumstances (from: Review of Medical Physiology (1995) Ganong WF)

The top diagram is the situation at rest. The extrafusal muscles are relaxed and not stretched. The afferents are nevertheless firing signals, as a consequence of the basic activity of the γ efferents. In the second figure, the extrafusal fibers are stretched and the muscle spindle is as well: the discharge frequency increases. On the contraction of the extrafusal fibers, the muscle spindle shortens and the discharge frequency decreases (third figure). The discharge frequency of the afferents can also increase without a change in the length of the extrafusal fibers: the intrafusal fibers shorten due to γ activation (fourth figure). The bottom figure shows the response of the muscle spindle to stretch, with increased γ innervation; the discharge frequency is much higher at the same stretch as in figure 2.

The foregoing deals with the response of the muscle spindle to the momentary length of the muscle, or the static response. There is also a dynamic response, however, or the response of the muscle spindle to the *change* in the length of the muscle. This is illustrated in figure 3. The nerve of the nuclear bag fiber (the Ia afferent) shows a strong response to the change in muscle length, while the nerve of the nuclear chain fiber (the II afferent) only responds to the momentary length of the muscle. In addition, as explained above, the nuclear bag fiber and the nuclear chain fiber are innervated by different γ efferents - the nuclear chain fiber by γ s efferents (γ *static* efferents) and the nuclear bag fiber by γ d efferents (γ *dynamic* efferents). The fact is that the Ia afferents in particular are extremely sensitive to innervation of the γ d efferents; the dynamic response increases strongly on contraction of the intrafusal parts of the nuclear bag fibre.

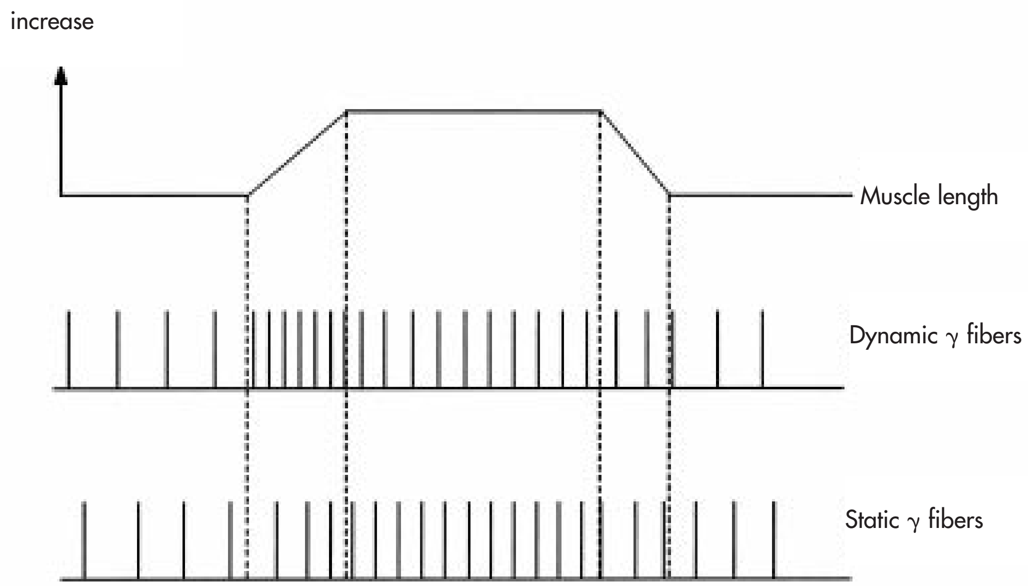

Figure 3: The responses of the afferents of the muscle spindle to changes in the length of the intrafusal fibers. Ia afferents (of the nuclear bag fiber) respond to the change in length, II afferents (of the nuclear chain fiber) to the momentary length of the intrafusal fibers.

Figure 4 shows an example of the specific response of the Ia and II afferents of the muscle spindle. On the left is a non-recurrent change in muscle length; the response of the II afferents increases proportionately with the change in length, the Ia afferents mainly respond during the change in length. On the right is an unusual form of length change, the sinusoidal muscle stretch. The change in length is only detected by the Ia afferents, which is important in the interpretation of the effect of vibration training, because it means that the response of the muscle spindle to a sinusoidal change in muscle length depends greatly on γ activity.

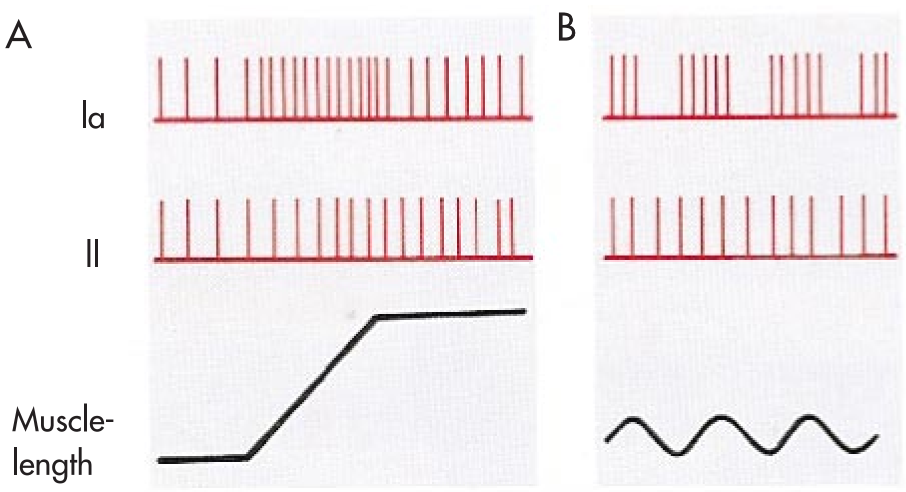

Figure 4: Responce of primary and secondary afferents to a linear and asinusoidal change in length. (from: Human Physiology (1983) Scmidt RF Thews G)

2.2 The Golgi tendon organ.

The Golgi tendon organs (GTO) are located in the transition from muscle fibers to tendon elements. In contrast to the muscle spindle, which is connected in parallel, the GTO is connected in series with muscles and tendons. As a result, it produces a response to both passive and active contractions. Figure 5 illustrates the location of the GTO. Tendon organs function as tension detectors, in contrast to muscle spindles, which function as length detectors. The central nervous system with its Ib afferents receives feedback from the GTO relating to the muscle tension in the muscles. It has traditionally been assumed that this feedback is negative, which means that it is assumed that the GTO inhibits the a efferents in response to an increase in muscle tension, which decreases as a result. In this manner, the GTO protects the muscle from excess tension. It has recently been suggested that this feedback may also be positive in some cases; an increase in tension reflexively facilitates a efferents, so that the tension increases further. This is explained at more length later in this chapter.

Figure 6 is a diagrammatic representation of the switching of the GTO and the muscle spindle. The GTO detects tension in the extrafusal muscle fibers and gives impulses to a efferents via an interneurone. It has traditionally been assumed that these impulses are inhibitive but, as stated above, there are indications that this connection does not always have to be inhibitive. The muscle spindle detects the muscle length and the change in muscle length, thereby more or less facilitating the a efferent. This connection is monosynaptic..

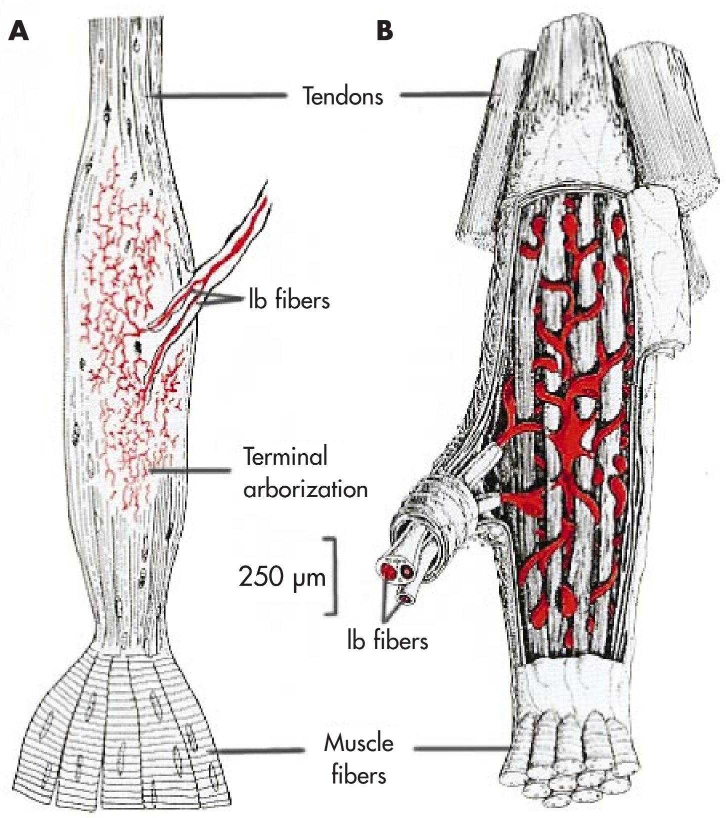

Figure 5: Diagram of the anatomical position of the Golgi tendon organ (from: Human Physiology (1983) Schmidt RF Tews G).

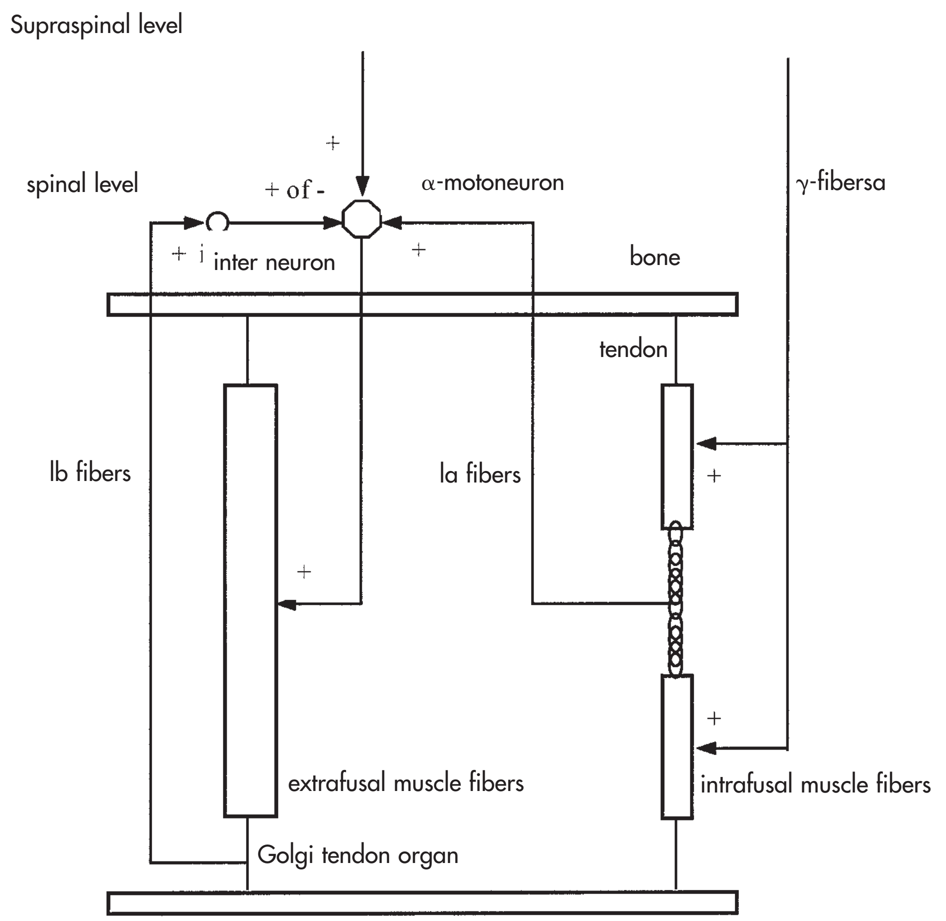

Figure 6: A diagrammatic representation of the switching of the Golgi tendon organ (GTO) and the muscle spindle with the α efferents. The muscle spindle has α monosynaptic connection with the α efferent, the GTO via an interneurone. The GTO gives the α efferents feedback about the tension in the muscle, the muscle spindle about the length of the muscle.

2.3 The myotatic reflex

Muscle spindles are at the basis of the myotatic reflex, which plays an important role in regulating posture. In brief, the myotatic reflex concentrates on keeping the present length of a muscle constant. When someone is in a squat (knees bent at an angle of 90 degrees, with a bar across the shoulders), the quadriceps muscles are reflexively contracted to maintain this posture. When a weight is added to the bar in this posture, a reflexive increase in the contraction of the M. quadriceps follows, so that the posture is maintained. The muscle spindle plays a central role in this process. The quadriceps muscles are stretched by the increased weight. The muscle spindles detect this and send signals to the spinal cord via Ia afferents. In the spinal cord, monosynaptic excitation of α efferents in the host muscle takes place: the muscle contracts and the posture is maintained as a result.

This reflex is very fast, due to the thick Ia fibers. In addition, these afferents innervate monosynaptic synergists and inhibit antagonists via an interneurone. The connections of the muscle spindle with efferents at spinal cord level is shown diagrammatically in figure 7. The muscle spindle of the extensor detects stretch, thus increasing the impulse frequency of the Ia afferents on the α efferent of the host muscle. At the same time, however, the α efferents of the antagonists (the flexors) are inhibited through an interneurone.

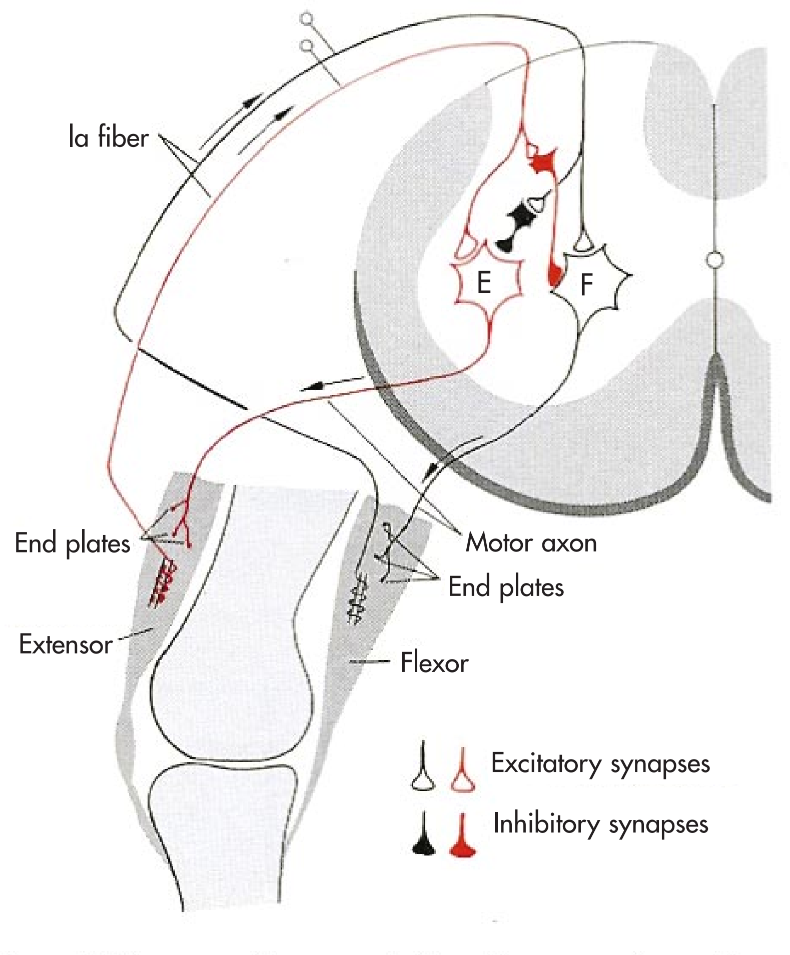

Figure 7: Diagrammatic representation of the connections of the efferent and afferent fibers of the muscle spindle at spinal cord level. E: the motoneurons of the extensors; F: the motoneurons of the flexors (from: Human Physiology)

The reverse applies to the flexors: the muscle spindle detects α shortening of the equatorial section and there is a decrease in the impulse frequency of the Ia afferents. The a efferents of the host muscle are less strongly facilitated and the α efferents of the antagonists are disinhibited.

As described above, there is a dual response from the muscle spindles. First of all, there is a static response that increases proportionately with muscle length. In addition, the muscle spindle has a dynamic response, which occurs on sudden changes in length. This is a high-frequency response, and it affects the motor units that can activate the muscle spindle.

When length changes are slow, the static response excites the low-threshold slow muscle fibers; the high excitation threshold of the fast muscle fibers is not exceeded. When length changes are fast, both slow and fast muscle fibers can be excited by the dynamic response.

The myotatic reflex is not/less active during random movements. After all, random movements would not be possible otherwise. The underlying mechanism is called the α-γ co-activation. In an isotonic contraction through the stimulation of α efferents, γ efferents are activated simultaneously. The length of the intrafusal fibers changes to such an extent as a result, that the equatorial sections of the muscle spindle (where the Ia afferents originate) retain an equal length. The response of the muscle spindle does not change, therefore. It is very important that this co-activation plays a role in building up force. The α-γ co-activation is also involved in an isometric contraction, for example, but the muscle does not shorten in this case, because the contraction is isometric

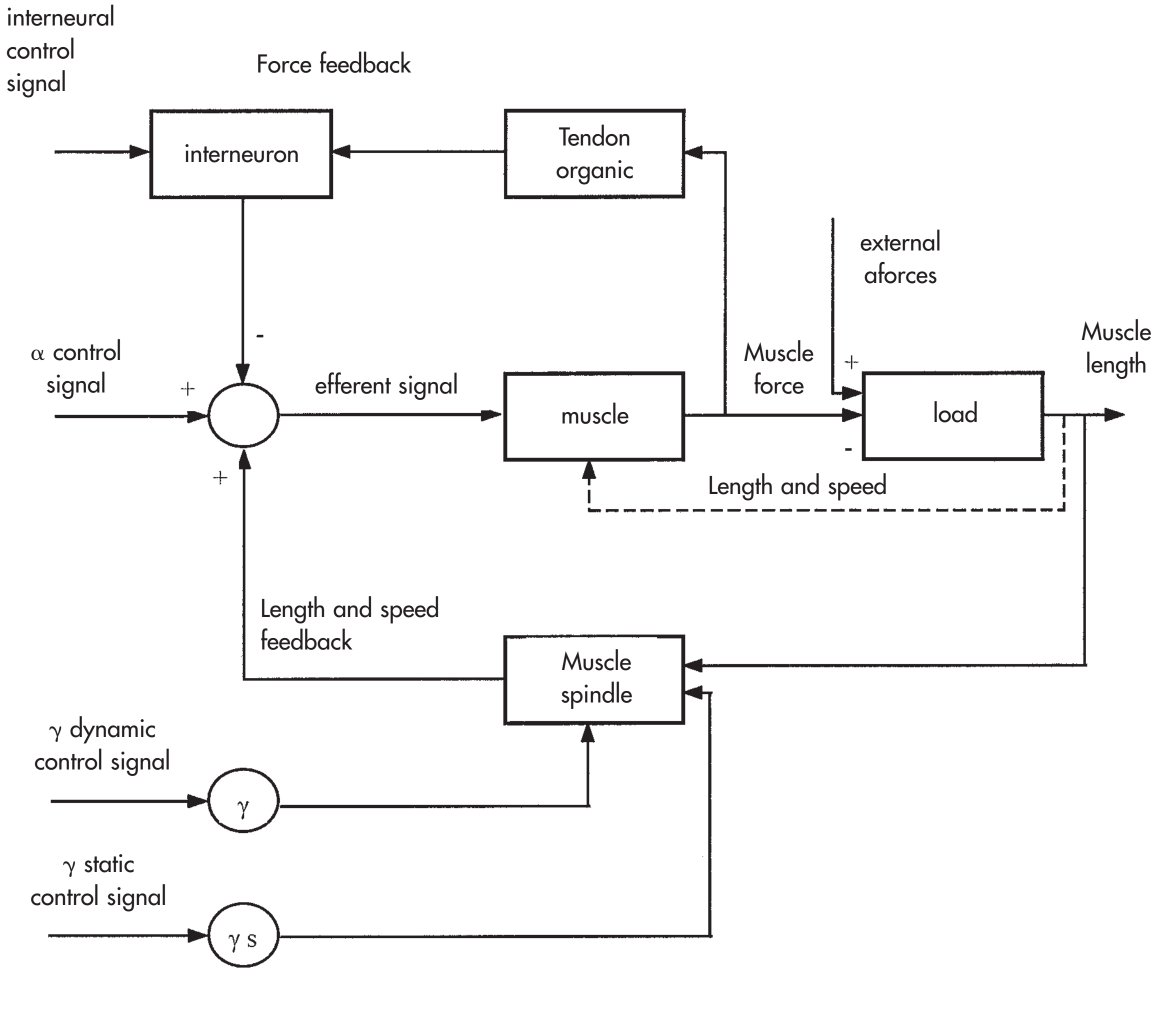

Figure 8: A diagrammatic representation of the tension and length feedback of the Golgi tendon organ and the muscle spindle respectively when lifting a load. The feedback from the muscle spindle is affected by the efferent control of γ efferents.

(a static leg press, for example). The muscle spindle does not shorten, while its intrafusal fibers do contract: the equatorial section stretches and discharges signals to α efferents in the host muscle. This produces a reflexive increase in force, known as the *load compensation reflex*. This is positive feedback: the isometric contraction causes the muscle spindle to facilitate the a efferents, strengthening the isometric contraction. Force is quickly built up as a result. The reason why this feedback does not lead to an uncontrollable increase in contraction force, is because the load compensation is lodged in a system of negative feedback - through negative tension feedback from the Ib afferents in the GTO, for example. The positive feedback from muscle spindles probably does not only play a role in fully isometric contractions, but also in contractions where part of the contraction takes place isometrically, when lifting a weight, for example. The reflex activity then increases, until the weight comes up. Figure 8 shows this in the form of a diagram. Both the extrafusal muscle and the intrafusal parts of the muscle spindle are innervated by α-γ co-activation. The contraction of the extrafusal muscle increases tension in the muscle, depending on the resistance of the load. The GTO detects this increase in tension. The contraction produces no movement when the load is heavy; the muscle length remains the same. The muscle spindle detects no difference in muscle length, therefore, but the equatorial section does shorten because the intrafusal parts contract due to the α-γ co-activation, thus increasing the impulse frequency of the Ia afferents. The facilitation of Ia afferents increases reflexively when the efferent volley of α efferents increases. This positive feedback persists until the load starts moving and the equatorial parts shorten. The GTO prevents the development of excessive tension in the muscle, by means of negative tension feedback. This feedback prevents uncontrollable increase of contraction during an isometric contraction.

The myotatic reflex depends on the pre-tension built up in the muscles prior to the contraction. It has been shown, for example, that a certain amount of tension develops in the muscles during the gliding phase of a jump from a height. This tension builds up through stimulation of γ efferents in both extensors and flexors (in the legs in this case). The rigidity (spring function) of the muscles increases as a result, but so does the stretch-sensitivity of the muscle spindles. At a certain stretch, the response of the muscle spindles is stronger. Experience and learning effect play a major role in this process; it is possible when catching a heavy ball that sufficient pre-tension has not been built-up in the first instance, but becomes sufficient after several attempts.

2.4 The tendon reflex

It has traditionally been assumed that the most important function of the GTO is to inhibit muscle activity. The GTO detects tension in the tendon on contraction and inhibits the α efferent of the host muscle by means of fast Ib afferents (see figure 8). It also facilitates antagonists.

These connections are multi-synaptic, so that the (mono-synaptic) myotatic reflex occurs more quickly. On rapid acceleration, the tendon reflex is therefore not fast enough to inhibit the subsequent contraction, which has been built up very rapidly. However, as stated above, there are indications that the GTO does not always have an inhibiting function.

2.5 New developments in force feedback

In the paradigm of the organization of the motor system at spinal level, the muscle spindle effects the negative displacement feedback, while the GTO effects negative force feedback. In the example of the squat referred to above (page 10), this means that the muscle spindle is focused on counteracting the movement as a result of the extra weight. The GTO ensures that the reflexive increase in contraction force does not become excessive, e.g. when a very large weight is suddenly added to the bar: negative force feedback.

Not all the results of recent studies agree with this paradigm, however. Recent indications have in fact been found that the force feedback of the GTO is not always negative, but is actually positive in certain situations in which the subject's own bodyweight is being carried, such as during stance or gait (Pratt 1995; Prochazka et al., 1997). The hypothesis for this positive feedback can be illustrated using figure 8 and the squat example on page 10. When an extra weight is placed on the bar, the load (in figure 8) increases. Muscle tension increases immediately as a result and this is detected by the GTO. According to the positive force feedback model, the GTO subsequently excites the α efferent, causing the contracting force to increase in order to carry the heavier load. According to the model, there is not an uncontrollable rise in contraction force, because the muscle spindle gives negative displacement feedback. As soon as muscle tension increases too strongly and the muscle contracts, the impulse frequency of Ia afferents decreases. It is further argued that there is a delay in the force feedback, which prevents an uncontrollable increase in force from being produced by the positive feedback (Prochazka et al., 1997).

It should, of course, be noted that the empirical underpinning for this model is limited to results achieved in research on cats, but it does show that the traditional paradigm of negative force and displacement feedback is not absolutely unquestionable. This has implications for the way in which the neuromuscular activity which develops during whole body vibration is interpreted. According to the traditional paradigm, this activity comes from negative feedback of displacement (Ia afferents), but in the force feedback model, positive feedback from the GTO cannot be excluded (Ib afferents). With a view to whole body vibration, it is very interesting that the positive force feedback mainly plays a role in inertially loaded muscles, which is to say in situations in which muscle tension increases due to an added load not as a result of contraction of the muscle itself, and only in situations when the body weight is being carried, during standing or walking, for example. Examples of this are jumping off an elevation or hopping – prolonged continual springing jumps. Of particular interest is Pratt's finding that positive force feedback has an important effect in the regulation of muscle tension during perturbations of the support surface.

3. What is vibration training

Vibration training was originally a modification of the tonic vibration reflex (TVR) produced by tendon vibration. The TVR is a reflexive contraction resulting from the very local stimulation of tendon or muscle (Bongiovanni et al., 1990 and other sources). The change in muscle length is detected by the muscle spindles in the muscle, which subsequently innervate the a efferents of the host muscle through Ia afferents, among other things. This activity is expressed in an increased EMG of the relevant muscle. The muscle is also able to supply some force in this way, without "higher" control. The generation of the TVR is used as a method of treatment in physiotherapy (Issurin et al., 1994).
Its application in sport required a more practical stimulation method, however. Nasarov, a Russian coach for athletes (gymnasts), was the first to apply vibration stimulation especially to help athletes. The vibration wave was applied to distal muscles and thus transmitted to proximal muscles by the tissue. Nasarov used a special device (see figure 9) to generate the vibration. The vibration frequency was 23 Hz.

Nasarov discovered that the vibration produced a rapid increase in the range of motion (ROM) of the joint in question and speculated on a shift in the pain threshold (Nasarov, 1991: in Künnemeyer and Schmidtbleicher, 1997), a line of reasoning later used by Issurin et al. (1994) to explain the improvement of the ROM. Furthermore, Nasarov hypothesized that vibration training improves blood circulation, among other things. Vibration as a means of training was later researched by various scientists. These studies did not usually focus on vibration training as a means of improving flexibility, but as a means of increasing muscular strength. Bosco's research team, for example, used a vibration platform on which the test subjects did the vibration training on their toes in a squat (Bosco et al., 1999). Issurin et al. used vibration training during regular weight training. After several weeks of training in this manner, Issurin et al. discovered an increase in force during a maximal contraction in the movement also used during training (Issurin et al., 1994).

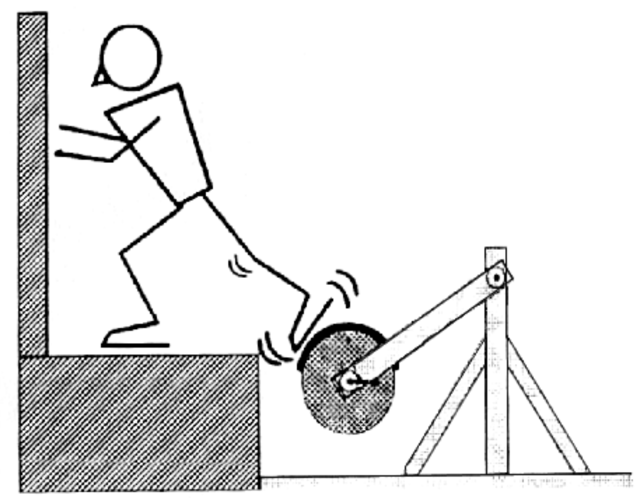

Figure 9: Vibration training using the Nasarov method (from: Kunnemeyer and Schmidtbleicher, 1997).

Bosco's research team did not only discover a training effect after several weeks of training, but also immediately after one single session of vibration training. Issurin and Tenenbaum (1999) were not able to produce this finding with their training method. Finally, a very recent study (Universität Bayreuth 2002, not yet released by the publishers) showed that the effect of vibration training is equal to maximal weight training.

The most important reason why unambiguity is lacking, is probably the inconsistency with which the vibration was applied in the various studies and the battery of tests used to determine the results. Nasarov's original method used a vibration frequency of 23 Hz. This frequency was used because of fear that the vibration would die out during transmission in the tissue if a higher frequency (such as in the TVR) were used. The use of a frequency of 23 Hz appears more or less arbitrary, however, which is why other researchers used other vibration frequencies. Bosco and his research group used a frequency of between 26 and 30 Hz, with an amplitude of between 4 and 10 mm. Issurin et al. used a frequency of 44 Hz and an amplitude of 3 mm. An additional complicating factor is that muscles are connected in series with tendons, which are also subject to certain changes in length. This gives rise to the question of whether vibration with a certain amplitude is capable of producing a change in muscle length.

In short, the explanation of the underlying mechanism of the TVR is not that complicated, and yet the explanation of the underlying mechanism of vibration training is complicated. The most important reason for this is that, in contrast to the TVR, the stimulus has a long way to go before it arrives at the sensor. The stimulus changes along the way, and this change is unquantifiable. A complicating factor is that the changes in the stimulus are stronger to the extent that the muscles are proximal to the vibrating source. It remains unclear, therefore, what stimulus each separate muscle group experiences during vibration. Irrespective of the changes in the stimulus, it still has the capacity to activate the M. multifidus up to thoracic level in a slightly squat posture. This was shown in a pilot study carried out by Dr. S. Verschueren at the Catholic University of Leuven.

4. What is the potential of vibration training?

4.1 4.1 Improvement of power and force is not only effected intramuscularly

The most important potential of vibration training is in the improvement of muscular strength, and this is therefore the focus of most studies of vibration training. As reviewed in the previous chapters, vibration produces reflexive contraction. The improvement of muscular strength actually has two main components. In the first place, it is possible to bring about intramuscular changes through intensive weight training. The contractional properties of the muscle tissue improve as a result, so that a maximal contraction provides more force and more power (with the right training). But apart from intramuscular changes, neurological adaptations are also capable of improving muscular strength; the control of muscle fibers is far from optimum in untrained subjects in particular. On the one hand, the neural drive that originates in the higher regions of the central nervous system may be inadequate to make all muscle fibers contract. On the other hand, apart from this excitory volley, there are various inhibitory influences that prevent all muscle fibers from contracting during a maximal exertion. There are indications that this inhibition has a particularly significant effect during fatigue (Woods et al., 1987). The consequence of these two factors is that not all motor units are recruited during maximal exertion. Magnetic resonance technology has shown, for example, that the whole muscle is not used during a maximal contraction; certain fibers remain unused. A striking illustration of this is that the force of contraction is increased by additional external stimulation during a maximal exertion (Gandevia, 2001). It has also been established that progression occurs in the contralateral leg or the contralateral arm when only one of the two limbs is trained (Enoka, 1997). A much-quoted study is that of Behm and Sale (1993A). They gave test subjects weight training for 16 weeks, during which training one leg made a rapid contraction (dynamic), while the other leg did the same but was blocked (isometric). Both legs had to be contracted quickly. At the end of 16 weeks, both legs had made progress on the contraction speed with which the auxotonic leg moved. The authors concluded that the intention of the movement is more important than the actual performance, a finding that endorses the importance of the neurological component of the trainability of muscle fibers. The bilateral deficit is another example. The bilateral deficit is the phenomenon that a maximal contraction with two limbs produces less force than the sum of the contractions of the individual limbs. Inhibition between the control of motor units of both limbs probably plays a role in this effect. Imaginary training is another striking example of the room for improvement that exists in relation to the control of motor units. Various studies discovered an increase in contraction force after imaginary training, which is to say movements made only in the mind. A clearer example of an increase in muscular power without intramuscular changes appears almost inconceivable (Gandevia, 2001).

It should be noted that the above findings occur most emphatically in muscle groups that are infrequently used. These effects are more difficult to find in well-trained athletes or are not present at all (Gandevia, 2001).

On the other hand, most research into muscle fatigue and contraction force is carried out with isometric contractions for reasons of practical feasibility. The recruitment of motor units is more complicated in non-isometric contractions, however, than in isometric contractions. Fatigue also develops differently. The recruitment of the number of motor units decreases much more quickly in non-isometric contractions (Ross, 2001). The addition of vibration does not produce higher contraction force in isometric contractions (Bongiovanni et al., 1990) but does do so in dynamic contractions (Issurin and Tenenbaum, 1999; Issurin et al., 1994). In other words, the potential for improvement of the neurological organization of motor unit recruitment is particularly high in non-isometric contractions.

4.2 The role of Ia feedback in developing force

There are five indications that the positive Ia feedback has an important effect on the development of force during an isometric contraction (Gandevia, 2001).

1. The firing of efferents decreases and becomes irregular under local anaesthetic, which switches off mainly small (and therefore fusimotoric) fibers.
2. Vibration on the tendon or muscle that generates the tonic vibration reflex during maximal voluntary isometric contractions increases the force delivered during fatigue.
3. The firing of axons of efferents proximal to a complete blockage of motor nerves is 30% lower than in a normal innervated situation. It indicates the upper limit of the facilitation of efferents by afferents, such as those of muscle spindles. It should be noted that this facilitation may also originate in other afferents.
4. The unloading reflex is reduced after fatigue. This may be the result of a decreased facilitation of efferents by Ia afferents.
5. The decrease in the firing frequency of motor units during a prolonged contraction is less strong when a movement is *imposed* during the contraction, on the joint over which the relevant muscle works.

The studies of Bongiovanni et al. (1990) illustrate the role of the Ia feedback in building up force. Bongiovanni et al. had a number of test subjects make a maximal isometric contraction of 60 seconds under very localized anaesthesia of the N. Peroneus, which switched off γ motor fibers. The lack of force and the low EMG at the start of the contraction were particularly striking in comparison with a normal contraction. The motor units were not capable of supplying a high initial firing frequency, as is the normal pattern in a maximal contraction. The Ia feedback appears to play an important role, especially in building up force. Nor did tendon vibration applied to the anaesthetized muscle produce any increase in force or EMG. Basic fusimotoric activity is necessary for Ia facilitation – evidence of the α-γ co-activation. In a later study, Bongiovanni et al. argued that Ia feedback does not only play a role in isometric contractions, but also in other voluntary muscle activity, especially if the contractions are explosive.

The role of the Ia feedback during activities like walking, jumping and running is embedded in what is known as the stretch-shortening-cycle (SSC) model. This model assumes that a short stretching phase takes place in the muscle during the said activities. As a result of the elastic properties of the muscle and tendon, but also due to a reflexive facilitation of a efferents caused by Ia afferents, this stretch is immediately followed by a concentric contraction (Komi, 2000). Muscle activity during fatigue is used to illustrate the importance of the stretch reflex, according to this model at least. During fatigue, α gap develops between the impact and the concentric contraction. A decrease in the stretch sensitivity of the muscle spindles is hypothesized as the most important cause of fatigue of the SSC. It was argued that this reduced stretch reflex is more likely to be the result of fatigue of intrafusal fibers than of reduced fusimotoric control.

Ross et al. (2001) confirmed the importance of the stretch reflex during walking and particularly during sprinting. In their opinion, it has been shown that maximal sprint performance is capable of substantial improvement, even apart from intramuscular changes. The surplus progression is interpreted by neural improvements, Ross et al. ascribing great potential to the stretch reflex. The stretch reflex can in fact be conditioned using a simple programme of repeated short stretches or one maximal isometric contraction (also see below: *The Ia feedback shows great plasticity*). This scope for potentiation is very interesting from the point of view of training, because (also according to these authors) the stretch reflex plays an important role in building up force during jumping or sprinting. First of all, the stretch reflex contributes to the development of force during the extension phase, as is also suggested in the SSC model. When the muscle is active prior to contact with the ground, the contribution of the stretch reflex to the development of force is increased somewhat. In addition, there are indications that training can promote the contribution of the stretch reflex.

The contribution of the stretch reflex to movements like walking, sprinting or jumping can be an important indicator of the potential of vibration training. It has to be assumed for this purpose, however, that the system of Ia feedback to a efferents is stimulated by vibration training and that a motor learning effect can develop, whereby this system gains in efficiency as a result of vibration training. The first supposition is undoubtedly the case in the generation of the tonic vibration reflex, because the vibration is applied to the tendon or muscle. A change in muscle length is then unavoidable. The stretch reflex is in theory and empirically an important catalyst for various contractions and it is clear that vibration training can facilitate the stretch reflex.

4.3 The Ia feedback shows very great flexibility

The stretch reflex has great potential for increasing its efficiency after a certain stimulus. Gollhofer et al. (1997) discovered that a remarkable increase in the stretch reflex occurs after an isometric contraction (60% MVC) lasting only two seconds. After an initial, very brief, decrease in the activity of the stretch reflex (0.2 seconds), the activity increases for a period of 20 seconds. The increase is strongest after one second. The Hoffmann reflex or H-reflex was also measured in this study. The H-reflex is important because this diagnostic method is used in the research into the effect of vibration training (see chapter 5). In contrast to the stretch reflex, the H-reflex is a reaction to an external stimulus. This stimulates the axons of nearby motor units on the one hand, and the low-threshold Ia afferents on the other. As a consequence, the EMG of the H-reflex produces two peaks. The first is caused by direct stimulation of the motor units, the second through the monosynaptic excitation of the efferents by stimulated Ia afferents. This reflex literally bypasses the muscle spindle and does not therefore measure changes in the sensitivity of the spindle. The H-reflex does, however, measure the efficiency of the Ia-a efferent synapse and the related pre-synaptic inhibition of Ia afferents. Although the H-reflex is therefore in fact dependent in part on the impulse transfer from Ia afferents, the reflex is considered to be a measurement of the excitability of the a efferent or, in other words, the net result of inhibition and facilitation: a rise in the H-reflex signifies potentiation of the motoneurone pool. The H-reflex and the stretch reflex have a different path following an isometric contraction. The stretch reflex increases for some time after an isometric contraction lasting 2 seconds, the H-reflex does not. The increase of the stretch reflex may be a result of a lowering of the excitation threshold of the muscle spindles. (Gollhofer et al., 1997). It is also possible that the efficiency of Ia afferents has increased after contraction: more transmitter is released by the Ia afferents in reaction to a high frequency volley of impulses (Ross et al., 2001).

Other studies have, however, found an increase in the H-reflex after an isometric contraction (Hamada et al., 2000A). The contractions were maximal in these cases. A maximal isometric contraction does in fact produce a decrease in the H-reflex, followed by an increase 4 minutes later. The increase in the H-reflex is greatest in type II fibers (Hamada et al., 2000B). A remarkable finding is that potentiation of the H-reflex has the same path as the increase in explosive force established after the same maximal isometric contraction (Güllich and Schmidtbleicher, 1996 in: Ross et al., 2001). Ross et al. hypothesize that that might well indicate that the stretch reflex makes an important contribution to explosive force (Ross et al, 2001). But, as stated above, the H-reflex is more likely to measure the net result of the facilitation and inhibition of the motoneurone, than the efficiency of the stretch reflex. The increase in the H-reflex may well be the result of disinhibition of the motor pool (due to fatigue of an inhibiting system, for example), or facilitation of other afferents. This is not in accordance with the assumptions of Wolf et al. (1995), who found an increase in the stretch reflex following a 240% conditioning programme (repeated short stretches) for the stretch reflex. They gave the plasticity of the Ia efferent synapse as the cause of the increase, which synapse is actually included in the H-reflex.

In summary, it is true that the stretch reflex can very quickly gain in efficiency, despite the above contradictions. The cause of this is unclear. If the Ia motoneurone synapse is the basis for this, the H-reflex is also an indication of an increased stretch reflex. The course of the potentiation of the stretch reflex or H-reflex is very variable and may well be dependent on the percentage of the MVC on which the contraction is carried out. The period between contraction and potentiation varies from 2 seconds to 4 minutes. The potential of the stretch reflex or the H-reflex for increased efficiency is important in the interpretation of the effects of vibration training, because vibration training is presumed to act at stretch reflex level. The effect that takes place after an isometric contraction may be the same as that which takes place after vibration training, which could explain the findings of Bosco et al. (1999 etc.), who found an increase in power after one single vibration session. This effect must of course be distinguished from a motor learning effect: temporary disinhibition or facilitation occurs with a short potentiation of the stretch reflex, while a motor learning effect results in a permanent, more efficient motor programme. This latter effect was established by Issurin et al. (1997 etc.) for example, who determined the effect of combined weight and vibration training. It is unclear to what extent the two effects are based on the same mechanism.

5. Research into the effects of vibration training

5.1 Effect on force, speed or power

This paragraph will consider the various studies that have established the effects of vibration training on force, speed or power. These studies can be divided into two categories. The first category focuses on the effect immediately after a single session of vibration training (the acute effect), while the other studies focus on the effect after a few or more weeks of vibration training, sometimes combined with weight training.
The first form of vibration training therefore speculates on a short-term facilitation of a potentiating system, such as the positive feedback from Ia afferents (see paragraph 4.3). This is comparable with the potentiation following a maximal isometric contraction. This effect changes into fatigue if vibration lasts longer. It has been shown that the positive Ia feedback quickly becomes exhausted, probably as a result of transmitter exhaustion, but other factors cannot be excluded (Bongiovanni et al., 1990; Bongiovanni and Hagbarth, 1990). The acceleration and the duration of the vibration are very important in this case, therefore. Potentiation can quickly change into fatigue.

The research into a structural effect of vibration training on force and/or speed does not speculate on temporary disinhibition or facilitation, but on the development of new, more efficient motor patterns, as a result of which more force or power can be provided without intramuscular changes. Almost all of these studies use submaximal or maximal contractions during the vibration training. By so doing, they speculate on the assumption that the total excitory input is much greater in this way than in normal weight training: *"creating a need for more motor control"*. In maximal contractions, the vibration stimulus results in the use of motor units that are normally left unused. The hypothesis is that a motor learning effect then develops with increased neuromuscular efficiency, possibly because mechanosensors (primary afferents of the muscle spindle) are able to convert a large volley of impulses more efficiently into the release of neurotransmitter.

Table 1 is an overview of the studies related to force, speed or power, classified by research into structural effect and acute effect. In the following paragraphs, these studies will be examined on the basis of table 1. The study carried out at the University of Bayreuth (2002, not yet released by the publishers) has not been included in table 1, because the final version of this study has not yet been published; title and journal are still unknown.

5.1.1 Acute training effect

The acute effect of vibration training immediately after a vibration session has been shown in a number of studies by Bosco et al. In the first of these studies (Bosco et al., 1999A), 12 boxers received 5 sessions of vibration training (VT; 30 Hz; 6 mm; 34 m/s^2), each lasting 1 minute, on one of their arms. The other arm received no VT. The VT arm was semi-flexed during the vibration session, while a weight of 2.8 kg was lifted. The power of the non VT arm did not increase, but did increase in the other arm (approximately 12%). The researchers speculated on a lowering of the excitation threshold of the reflexes, which might possibly produce increased efficiency in random movements. This conjecture appears to have been confirmed, because the EMG/power ratio only improved in the VT arm ($P<0.01$). These results were confirmed by a comparable study by Bosco et al. (1999B). This study involved 14 female volley ball players. One leg received vibration training; 10 sessions of 1 minute, with one minute rest between each application. The vibration frequency used this time was 26 Hz, the amplitude 10 mm and the acceleration 54 m/s^2. The test subjects were given vibration while standing on their toes on the vibration platform with one leg; the knee flexion was 100 degrees. In this study too, a significant acute effect of vibration was found on power during a maximal leg press; power increased between 5.8 and 7.6% at various percentages of the 1 RM. The researchers put forward a new argument in this article. Vibration training causes the same effects as explosive weight training i.e. improved neuromuscular efficiency. The stimulus for explosive training consists of increasing the power of gravity, by continuous jumping for example, or by jumping off a platform. In the case of vibration training, this force is many times greater than in explosive weight training and training effects therefore occur much more quickly.

These studies are concerned with potentiation of the motor pool (probably via disinhibition) or with potentiation of a reflex that produces load compensation, for which the primary afferents of the muscle spindle appear to be the most suitable candidates, in the opinion of these researchers. It is stated, therefore, that the vibration training causes minor changes in muscle length, although this assertion is not supported empirically (Bosco et al., 1999B). There have been previous hypotheses that Ia afferents are able to convert a high-frequency volley of impulses into the release of neurotransmitter following a maximal isometric contraction (Ross et al., 2001). The same, temporary effect might take place after a short vibration session. The length of time until the effect probably varies widely, depending on the duration and intensity of the stimulus, as previously established for potentiation after isometric contractions. It is remarkable, therefore, that Bosco et al. did not indicate in either study what the time had been between the vibration training and the measurement of the effect, which is essential information for the reproducibility of these studies.

	Author and title	Vibration	Exercise	Effect	Discussion
Acute effect	Bosco et al. 1999: *Influence of vibration on mechanical power and EMG in human arm flexor muscles*	30 Hz; 6 mm; 34 m/s^2; 5 x 1 min.	vibration applied by hand, elbow in 140° flexion, lifting weight of 2.8 kg	increase power dynamic flexion elbow (exact increase not given, ≈ 12%	Caused by lowering of excitation threshold of reflexes; resulting improvement in random movements.
	Bosco et al. 2000: *Hormonal responses to WBV in men*	26 Hz; 4 mm; 170 m/s^2; 10 x 1 min.	on platform, standing on toes, knee in 100° flexion.	ncrease height CMJ (4%) and W (7%) on dynamic leg press (70% 1 RM); increase plasma T, GH and C.	ncrease plasma T gives facilitation at synapse level.
	Bosco et al., 1999: *Adaptive responses of human skeletal muscle to vibration exposure*	26 Hz; 10 mm; 54 m/s^2; 10 x 1 min.	on platform, standing on toes, knee in 100° flexion.	increase in power on dynamic leg press (5.8 to 7.6%) ; increase in force is less strong	Acceleration during vibration is many times higher than during normal training
	Issurin and Tenenbaum (1999) *Acute and residual effects of vibratory stimulation on explosive force in elite and amateur athletes.*	44 Hz; 3 mm; 30 m/s^2. vibration applied during 3 maximal contractions	flexion of the elbow. see text for research method.	more power during vibration (10.4%), but no effect immediately following vibration.	n this study, in contrast to TVR, vibration produces excitation of many Ia afferents which activate previously inactive motor units
	Künnemeyer en Schmidtbleicher *Die rhytmische neuromuskuläre stimulation (RNS).*	3 Hz; ? mm; 3 x 2 min.	alternating stretching (10 s) and relaxation (10 s) of the calf muscles, as in Nasarov.	reduced jump height of drop jump until 30 min. later EMG reduced, not significant. H-reflex reduced until 30 min. later	vibration causes a net inhibition of the motoneurone, judging from the decrease in H-reflex.

Structural effect	Spitzenpfeil; in: Mester et al., 1999: *Biological reaction to vibration-implications for sport*	24 Hz; 2.5 mm; 3 days vibration alternated with no vibration for 3 days, 16 days in total.	vibration during weight training: drop jumps, single-legged squats, squat jumps	increase in force on static leg press (43%), increase in squat jump height (23%) Increase in plasma CK in first days: subsequent normalization and increase in force after 8e VT.	vibration makes great demands on neuromuscular system, mainly to attenuate vibration and to maintain balance. Modification leads to progress.
	Bosco et al.., 1998: The influence of WBV on jumping performance	26 Hz; 10 mm; 54 m/s^2; 5 x 90 s; every day for 10 days.	on platform, changing from semi-squat to one-legged squat, on the toes.	increase in average height 5s CJ (12 %). No increase in CMJ.	potentiation of stretch reflex, rise in GTO threshold, as result of extremely high stretch load (54 m/s^2)
	Schlumberger et al., 2001: *Krafttraining unter vibrationseinwirkung.*	25 Hz; 6 mm; 3 times a week for 6 weeks. VT on one leg, not on other.	during one-legged squats, 4 series of 8-12 maximal repeats	increase in force (6.5%) not different to traditional WT (6.4%).	vibration may have both facilitating and inhibiting effect.
	Issurin et al., 1994: *Effect of vibratory stimulation training on maximal force and flexibility.*	44 Hz; 3 mm; 30m/s^2; 3 times a week for 3 weeks.	during isotonic flexion of elbow, rising from 80% to 100% 1 RM, 6 series.	increase in maximal force in isotonic flexion (49.8%). and flexibility (8.7%) no increase in isokinetic contraction.	motor learning effect caused by recruitment of inactive motor units.
	Weber, 1997: *Muskelstimulation durch vibration*	25 Hz; 3 mm; during weight training 2 series of 8 repetitions 80% 1 RM; variable training frequency.	1. ring exercise (M. deltoidius) 2. rowing exercise (M. latissimus dorsi); both exercises sitting	1. 27 percent increase 1 RM after 12 weeks training (variable frequency) 2. an increase of 34% of the 1 RM after 8 training sessions (2 x per week)	activation of mechanoreceptors and increased muscle tone due to vibration; synchronization of this with voluntary movement at certain frequency

Table 1: An overview of the studies of the acute and structural effects of vibration training on force, speed and/or power.

The hypothesis of Bosco et al. that vibration training (as they implemented it) produces the same effect as weight training gives vibration training much greater practical relevance. If this is the case, a motor learning effect would be involved that is not transitory, but results in a permanent, more efficient motor pattern. The question is whether effects of this kind can take place as quickly as Bosco and his assistants presume. It has traditionally been assumed that an effect of this kind can only develop after a period of weeks. It would appear as if the effect develops more quickly with vibration training.

In a recent study from Bosco's research group (Bosco et al., 2000) an attempt was made to provide different grounds for the effects of vibration training. An increase of the concentration of testosterone and growth hormone was found in the blood after 10 minutes of vibration training. An increased testosterone concentration could cause facilitation at the level of neurotransmitters. Furthermore, a relationship has been shown between testosterone concentration and explosive force, although it has not been demonstrated that this relationship is a causal one. An increase of 7% in power on a dynamic leg press was also established. But in this case too, the researchers were unable to indicate whether this effect was only temporary or resulted in a structural increase in neuromuscular efficiency.

Other researchers have been unable to establish the acute effect of vibration training. Issurin and Tenenbaum (1999), for example, were unable to establish any acute effect after vibration training, although they applied vibration training *during* normal, maximal weight training. As stated above, it would appear that intramuscular fatigue, or fatigue in the more central motor control, obstructs any potentiating effect. In addition, the vibration in this study was only applied on three maximal contractions, much shorter than Bosco et al. did. Künnemeyer and Schmidtbleicher (1997) also found no acute improvement in jump height after vibration training (23 Hz, 3 times 2 minutes for each leg, using the Nasarov method). The jump height (drop jumps) decreased significantly and a significant decrease in the H-reflex was also discovered, of 43% at the most. This last finding indicates that the vibration training had caused a net inhibition of the motoneurone pool, or an exhaustion of transmitter in the Ia-motoneurone synapse. The latter might indicate that the vibration went on too long to be able to produce potentiation, although the vibration training was no longer in total than in the studies by Bosco et al. It was very important that these researchers did not apply whole body vibration. The test subjects received vibration training as illustrated in figure 9. The muscles carried no load and muscle tension was low as a result. These researchers established for this vibration training that reflexive muscle activity actually took place, originating from Ia afferents, but the stimulus was apparently unable to effect potentiation in this case.

5.1.2 Structural training effect

The structural effect of vibration training was researched by Bosco et al. in 1998. In this study, the experimental group (n=7) received 10 vibration training sessions every day for 10 days, consisting of 5 repetitions of 90 sec (increasing to 2 min) of vibration. The vibration frequency was 26 Hz, the amplitude 10 mm and the acceleration 54 m/s^2. The control group received no training. After 10 days, a group-by-training effect was found in the 5 sec continuous jumping test (5 CJ). There was no effect in the counter movement jump (CMJ). As a reason for the absence of an effect on the CMJ, the authors reasoned that the angular velocity of the knee and hip is much less in a CMJ than in the 5 s CJ, for example. It was argued that, at that low speed, the feedback from 1a afferents plays a much less important role in the build up of force during the conversion of the eccentric into the concentric phase, as is the case in a stretch-shortening-cycle contraction, for example (Komi, 2000). The authors therefore assumed that vibration training produces a motor learning effect, whereby the positive feedback from Ia afferents is potentiated. It is noteworthy that Bosco et al. gave their test subjects vibration training every day, without intervening rest days. This ignores the findings of Mester et al. (1999), who determined that there is considerable muscle damage after vibration training. Mester et al., however, used vibration training in combination with maximal weight training and it would appear obvious that this combination produces greater intramuscular damage than the unloaded vibration training of Bosco et al.

The above study by Bosco et al. is the only scientific publication in which the structural effects of static and unloaded vibration training have been established. Other studies combine maximal or submaximal weight training with vibration training and speculate on a motor learning effect. An adaptation takes place due to an increased excitatory volley originating in Ia afferents, so that the control of contractions becomes a more efficient process: the motor programme that controls movement is capable of converting a high frequency excitory volley more efficiently into contraction. The underlying mechanisms can only be speculated on. It is clear, however, that this effect can only play a role in explosive maximal contractions, when there is maximal control from higher centres and at spinal level.

The first study to combine vibration training with weight training dates from 1994 (Issurin et al., 1994). After weight training with vibration (3 weeks, 3 times a week, 44 Hz, 3 mm, 30 m/s^2), these authors found a 46% progression in 1 RM, while the same weight training without vibration only produced 16% progression. The weight training consisted of 6 series of bench pulls (see figure 10), whereby the weight was stepped up from 80 to 100% 1 RM. In each series, repetition continued until exhaustion. The weight training with vibration was carried out using a special device, with which the vibration could be applied to the weight exercises. The test subjects did the weight training therefore, but with a vibrating handle.

In a later study (Issurin and Tenenbaum, 1999), these authors attempted to unravel the mechanism underlying this effect. They discovered in this study that *power* increased by approximately 10.2% *during* vibration, compared with a situation without vibration. It was argued that at the vibration frequency used (the same as in 1994), the afferent excitory inflow is synchronized with the random control of the motor pool, so that greater power can be delivered *during* the vibration. This study measured the power and not the force measured on an explosive bench pull, which is consistent with the theory that positive feedback from Ia afferents mainly plays a role in the rapid build-up of force at the start of a contraction (Bongiovanni et al., 1990 and others). The measurement of power is therefore more relevant than force.

The results of this research are not supported by other studies. Although it is true that Bongiovanni and Hagbarth (1990) established that the tonic vibration reflex can briefly intensify both the EMG and the force of a random isometric contraction, this effect disappears as soon as the contraction is maximal. When there is fatigue, vibration does have an effect on a maximal contraction, but then mainly on the EMG (see figure 11). This research group later discovered that the excitory effect of vibration disappears and becomes strongly inhibiting (see figure 12) under prolonged vibration on the tendons of the dorsiflexors of the ankle. There is naturally a great difference between the TVR and whole body vibration: the vibration is applied to the tendon with a frequency of 150 Hz. Issurin and Tenenbaum argued that vibration, as used by them, produces a much more widespread excitation via Ia afferents, so that fatigue occurs much less quickly in these afferents. Samuelson et al. (1989) also established that vibration is more likely to have an inhibiting effect in the long term. They found that the maximal force on an isometric leg press was no different during vibration than in the same situation without vibration, but that the time that this maximal contraction could be maintained did decrease. It should be noted that a vibration frequency of 20 Hz was used in this study which, according to Mester (1997), is a frequency at which the body attempts to attenuate the frequency instead of responding with reflexive contractions.

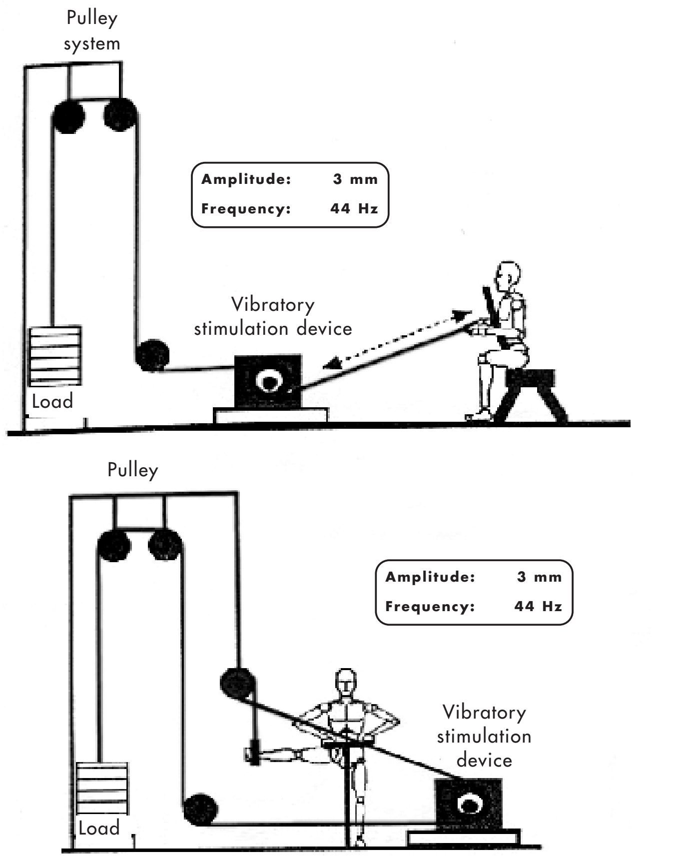

Figure 10: Issurin et al., (1994): Combined weight and vibration training (top) and vibration training to increase flexibility (bottom)

The results of a recent study by Schlumberger et al. (2001) are inconsistent with those of Issurin et al. (1994). Schlumberger et al. found no difference between traditional weight training and weight training with vibration.

The training programme lasted 6 weeks in this study and there were 3 training sessions a week. The test subjects did 4 series of between 8 and 12 squats (12 RM) with one leg; they did the same exercises with the other leg, but then with vibration. The vibration was administered with a frequency of 25 Hz and an amplitude of 6 mm. The researchers took the greatest force during an explosive isometric contraction of approximately 2 seconds as a measure of the maximal force. The steepest section in the force/time curve was used as the norm for explosive force. After 6 weeks of combined training, 6.5% progression ($P<0.01$) had been achieved in maximal force, and a 6.2% increase ($P<0.01$) after 6 weeks of traditional training. The modest difference in progression between the two programmes was not significant. The increase in explosive force was 4.5 and 2.8% respectively. Neither effect was significant and, although the progression with the combined training appeared somewhat stronger, the difference in effect between the two training programmes was not significant. The results of this study are remarkable, because they are diametrically opposed to the results of Issurin et al. Schlumberger et al. postulated a number of reasons that might be able to explain the differences between their own study and Issurin et al., but called the validity of these reasons into question in passing. For instance, the maximal force in Schlumberger et al. was measured on the basis of maximal isometric contractions, while the training actually consisted of dynamic contractions. Schlumberger et al. asserted that isometric contractions are necessary as a testing method, because the test/retest variation is then very low. According to them, the test/retest variation is much too high when dynamic contractions are used, particularly in trained subjects. They also argued that measurements with isometric contractions are outstandingly capable of differentiating between the effectiveness of two dynamic weight training programmes. Other studies are diametrically opposed to this opinion, however (Behm and Sale, 1993A; Behm and Sale 1993B).

It is better to measure the rate of force development during an isometric contraction, as Schlumberger et al. also established in their study. It is true that there was a difference between the vibration and the non-vibration groups, but this difference was not significant. A dynamic contraction like a CMJ could possibly have demonstrated a significant effect. The possibility cannot be ruled out that test subjects are not able to build up force with maximal speed in an isometric contraction. After all, the intention is to make an isometric contraction and intention plays a very important role in the motor programme that is triggered (Behm en Sale, 1993A). The measurement of the height of a CMJ or the power on a dynamic leg press, as previously carried out by Bosco et al. (2000), may well have been a more robust method of establishing an effect.

Schlumberger et al. themselves suggested that a possible cause of the lack of effect could have been that they used 10-12 repeats in their study (with a maximal weight, or 8-12 RM), while Issurin et al. only did a few repeats at 80 to 100% of 1 RM. It cannot be ruled out, in the light of the findings of Bongiovanni et al. referred to above, that the facilitating effect of the vibration is only enjoyed when there are few repeats, while the vibration more probably has an inhibiting effect when there are more repeats (figures 11 and 12). In other words, vibration training applied with fewer repeats and a higher weight, might well have produced a result.

Schlumberger and his fellow researchers also remarked in their manuscript that it is possible that Issurin et al. did find effects of vibration training, because they applied the training to the arm muscles, which have a higher percentage of fast muscle fibers than the leg muscles. When this is coupled with the knowledge that afferent volleys mainly affect the fast motor units as a result of vibration,

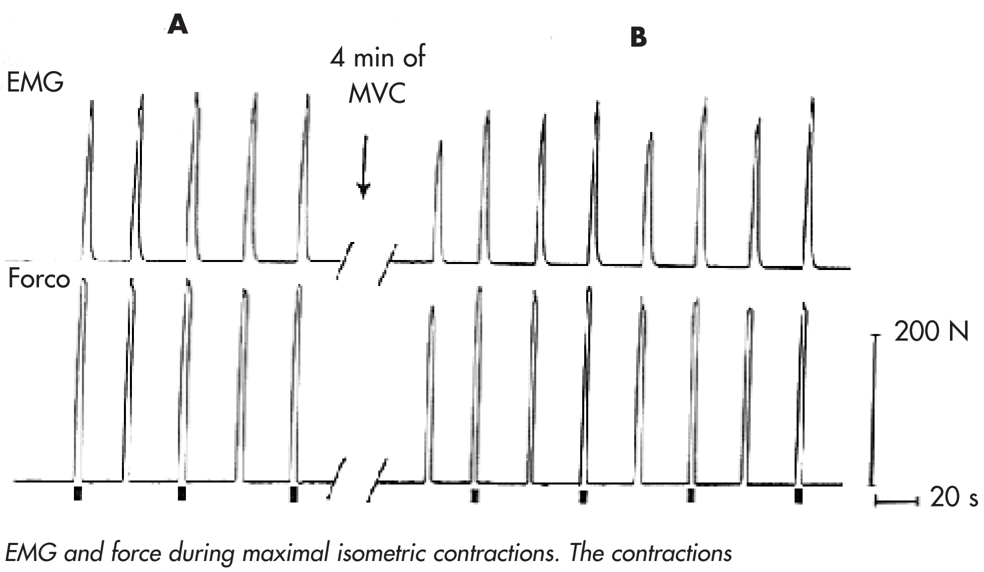

Figure 11: The EMG and force during maximal isometric contractions. The contractions marked with a black square were carried out with tendon vibration (100 Hz). A: contractions without fatigue; B: contractions after a maximal isometric contraction of 4 minutes.

it is quite feasible that combined weight training and vibration training have less effect on the muscles with a low percentage of fast fibers. The counter argument of Schlumberger et al., however, was the results of an as yet unpublished study, in which vibration was applied to a movement using chest and arm muscles. This study too found no greater increase in maximal force when vibration was used.

On the other hand, these authors did theorize that the excitation of the proprioception might be a force-promoting effect of vibration training. Proprioception training can bring about an improvement in explosive force (Gollhofer, 1999: in Schlumberger et al., 2001). It is difficult to remain in balance during weight training with vibration in particular, so that proprioception is additionally stimulated in this situation. This is consistent with the mechanism which Mester et al. (1999) speculate on as being the underlying mechanism for the effect of vibration training in combination with weight training: *"the need for more motor control"*. The foregoing is not contradicted, but is also not confirmed by the results of Schlumberger et al., because the explosive force increased more strongly after vibration training, but the difference was not significant.

The results found by Schlumberger et al. are refuted in a very recent publication (Universität Bayreuth, 2002, not yet released by the publisher). In this study, 57 test subjects divided into three groups underwent a training programme of 7 weeks. The first group did traditional weight training with 8-12 maximal repeats. The second group received vibration training and the third group did not train. The total time spent on weight training (the net time required for the repeats) was equal to the duration of the vibration training. The test subjects from groups one (with traditional weight training) and two (with vibration training) did three exercises, in which the M quadriceps femoris, the M latissimus dorsi and the M pectoralis major were trained in succession. It is very important that the test subjects did make contractions during the vibration training (one-legged knee bends for the M quadriceps), but these contractions were not maximal, in contrast to the study by Schlumberger et al. Both test groups trained twice a week for 7 weeks.

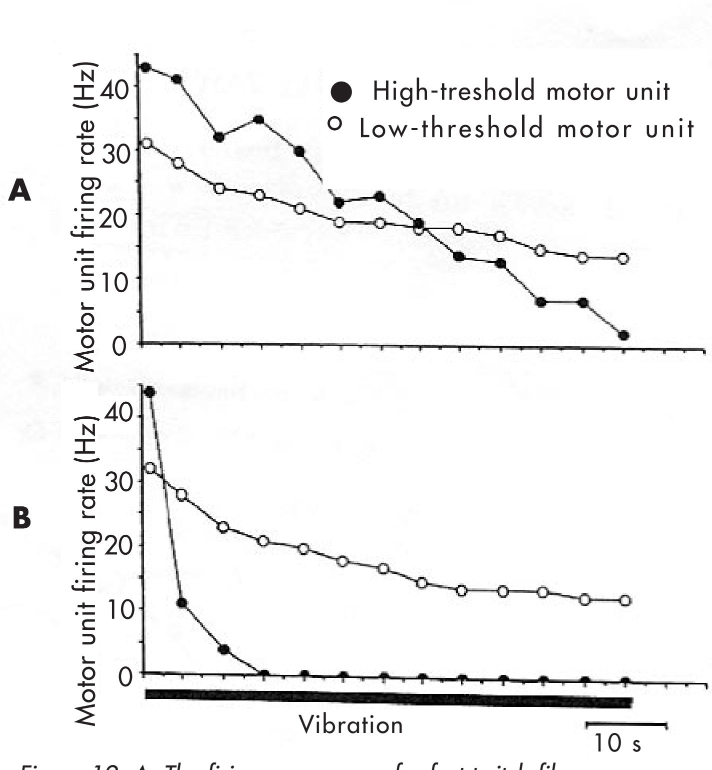

Figure 12: A: The firing rgequency of a fast twitch fiber (solid circles) and a slow twitch fiber (open circles) during a maximal contraction of 1 minute. B: The firing freguency of the same fibers, now during tendon vibration of 100 Hz.

There was no significant difference in training progression between groups 1 and 2 after this training period. It is still unclear whether the researchers measured training progression with isometric contractions or dynamic contractions. Also unclear is the effect of the different exercises that the two groups did: group 1 did exercises on a machine or with loose extra weight (squat), while group 2 did floor exercises. There are more degrees of freedom in the latter case, so that there is a "*need for more neural control*". Exercises of this kind produce a greater training effect.

The most important difference to the research done by Schlumberger et al. is that the vibration training in the above study was not combined with maximal weight training, but with sub-maximal contractions. The study found no significant difference between combined maximal weight training and vibration training, and maximal weight training alone. The study by the University of Bayreuth also found no difference between the combined weight and vibration training on the one hand, and weight training on the other. Only here, the combined weight training was not maximal. Maximal weight training combined with vibration training appears to provide no advantage over sub-maximal weight training combined with vibration training. This is completely contrary to the assumptions of the Issurin research team, that vibration training combined with maximal weight training results in an increased excitory volley on the α efferents, leading to the recruitment of motor units which would not have been active without vibration.

A longitudinal case study by Spitzenpfeil is referred to in a general article by Mester et al. (1999). In this study, an alpine skier received 16 days of weight training, with alternating 3 day periods of vibration and non-vibration (figure 13). The non-vibration period was filled with general weight training exercises like squat jumps, drop jumps and one-legged squats. The athlete also did these exercises during the vibration period, but then on a vibrating plate. The creatine kinase (CK) concentration in the blood had increased after the first period with vibration (24 Hz, 2.5 mm); an indication that the training load had caused much muscle damage. Force (static leg press) also decreased in this period, therefore. After the second period, there was again a slight increase in the CK concentration and a small increase in isometric force (after 6 training sessions). No real increase in force took place until after the third period, when there was a rise from 2700 to 3500 N. These results are somewhat inconsistent with those of Issurin et al., who indicated in a supplementary report to their 1994 study that the increase in force at the commencement of a vibration training schedule of three weeks is linear from the start of the training schedule. There is, therefore, no initial fall in maximal force in the test subjects in their study. It should be noted that the two researchers used different tests to evaluate the effect of vibration training. Spitzenpfeil used an isometric leg press, Issurin et al. used an isotonic maximal contraction of the flexors of the elbow. This is an important point, because the effect of vibration of a certain muscle group varies with different contractions of the same muscle group. After exhaustive vibration training of the leg muscles, the jump height in a maximal jump has already recovered after 10 seconds, but the force on an isometric leg press is still lower when 2 minutes have passed (Rittweger et al., 2000).

It is also remarkable that these researchers established an increase in isometric force, while this is not probable on the basis of the theory and on the basis of previous research (Schlumberger et al., 2001). It should be noted that the training volume used by Spitzenpfeil is much higher than that used in other studies and that it is only a case study: Mester et al. pointed out that no effects were established in other experiments from the same laboratory. There are strong individual differences in the effect of vibration training, therefore.

Finally, in another longitudinal case study, Weber (1997) found progressions of 27% (1 RM with vibration) and 24% (1 RM without vibration) after 12 weeks of alternately one or two sessions of vibration training per week (25 Hz, 3 mm). In contrast to Mester et al., Weber found no reduction in force during the first weeks. The reason for this is probably the lower training frequency in Weber's study. Weber also remarked that no progression is achieved with a training frequency of once a week.

5.2 Effect on flexibility

Nasarov, the first researcher to experiment with vibration as training, was primarily concerned with the effect on flexibility. He found that stretch exercises with vibration gave a greater increase in flexibility than stretch exercises alone (Künnemeyer and Schmidtbleicher, 1997).

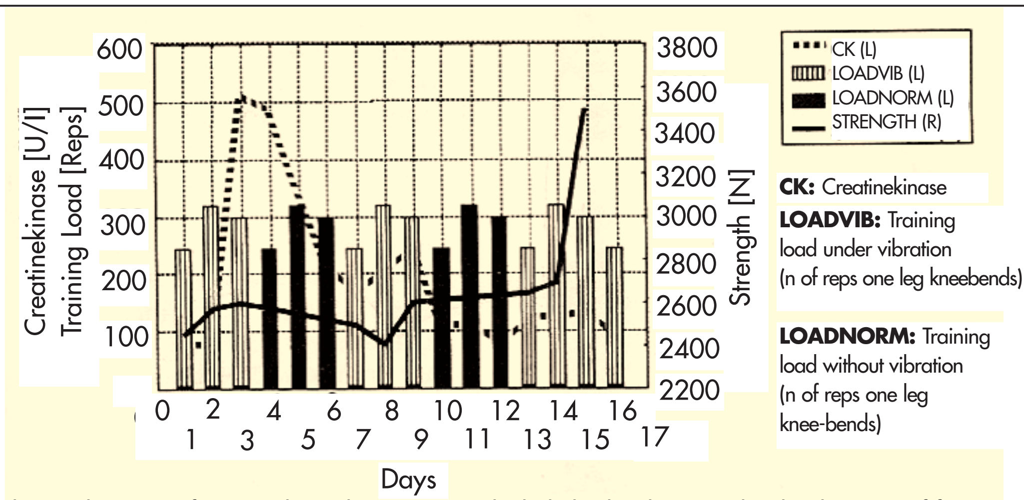

Figure 13: The combination of maximal weight training and whole body vibration: the development of force and the course of muscle damage. The striped columns show the days thet training was done with vibration; the black columns show normal weight training (from Mester et al., 1999).

The underlying mechanism of the effect on flexibility was sought in a shift of the pain threshold and the stimulation of Golgi tendon organs, causing the inhibition of the contraction (Issurin et al., 1994). Recent studies on the subject of flexibility appear to indicate the former. Increasing flexibility using stretch exercises has no effect on the length of the muscle or on the moment of contraction of the muscle in opposition to the stretch. The increased flexibility has a central cause, viz. an increased stretch tolerance (Magnusson et al. 1998; Halbertsma et al., 1999; Magnusson et al., 2000). This is probably also the cause of increased flexibility after vibration. The flexibility of the muscle itself does not change until after a warming-up, as a result of the increased fluid content of the muscle (Wiemann and Hahn, 1997). This is confirmed by the results of a study by Ribot-Ciscar et al. (1998). After tendon vibration (80 Hz for 30 seconds), a stretched muscle was experienced as being less stretched than it actually was, which is an indication that it is more probable that vibration produces centrally localized neural changes than that the properties of the muscle itself change. The increase in the stretch tolerance does not have a preventive effect on avoiding injury (Pope et al., 2000). A warming-up, preferably without eccentric contractions (cycling is preferred to walking), is more advisable in this respect (Wiemann and Hahn, 1997).

The use of vibration training to extend the range of motion is extremely interesting for athletes who require high flexibility, such as gymnasts. The extension of the ROM was not only established by Nasarov and Issurin et al., but was also confirmed later by Künnemeyer and Schmidtbleicher (1997) (see table 1).

5.3 Other effects

There are strong indications that vibration prevents a loss of bone intensity. Flieger et al. (1998), for example, found that vibration reduced the loss of bone density in rats whose ovaries had been surgically removed. This is consistent with Rubin et al. (2001, Nature magazine), who established higher bone density in sheep who had undergone vibration at a very low acceleration (0.3 g) for a period of one year. Another animal experiment (Falempin and In-Albon, 1999) found that vibration partially prevents the reduction of a number of qualitative properties during inactivity.

One acute effect of tendon vibration (as also applied in stimulation of the tonic vibration reflex) is a change in proprioception. The rest/firing frequency of most 1a afferents has decreased after tendon vibration (80 Hz for 30 s), which also applies to the sensitivity to stretch. The former has returned to basic level after 40 s, the latter after 14 s. The change in length detectors influences the perception of movement. Movements are experienced as being three times as fast as in reality, especially if both agonists and antagonists undergo vibration (as is the case with *whole body vibration)*. This may be an explanation for the observation that people feel fitter after a vibration session (Kelderman, 2001). This feeling may be further reinforced because vibration affects pain perception. There are indications that sensations of pain have decreased during and after vibration (Issurin et al., 1994).

5.4 Harmful consequences

Prolonged exposure to vibration, particularly on the shop floor, increases the risk of cognitive changes, acrophobia, low back trouble, visual limitations and epilepsy, among other things (Mester et al., 1999). This refers to years of exposure to vibration, however. The frequency of the vibration plays a key role in the possible risks of prolonged exposure to vibration. The resonance frequency of vital organs is between 5 and 20 Hz. The body's strategy in response to vibration frequencies of this kind is to attenuate the vibration as much as possible. At vibration frequencies of between 5 and 20 Hz, what is known as the transmission factor is lowered to such an extent that the vibration cannot transmit itself throughout the body as long as the amplitude of the vibration remains within certain limits. The vibration attenuation is no longer adequate above 24 Hz and it becomes more difficult to retain balance. This can be clearly seen in the graph showing the movements of the upper body during a vibration session: the anomalies in balance become increasingly greater above 24 Hz (see figure 14). The danger of possible damage to vital organs is reduced, however, because the resonance frequency of those organs has been exceeded. Vibration with frequencies of between 5 and 20 Hz is not advised, therefore, on the basis of these results (Mester et al., 1999). Vibration equipment with these frequencies is dubious as a result.

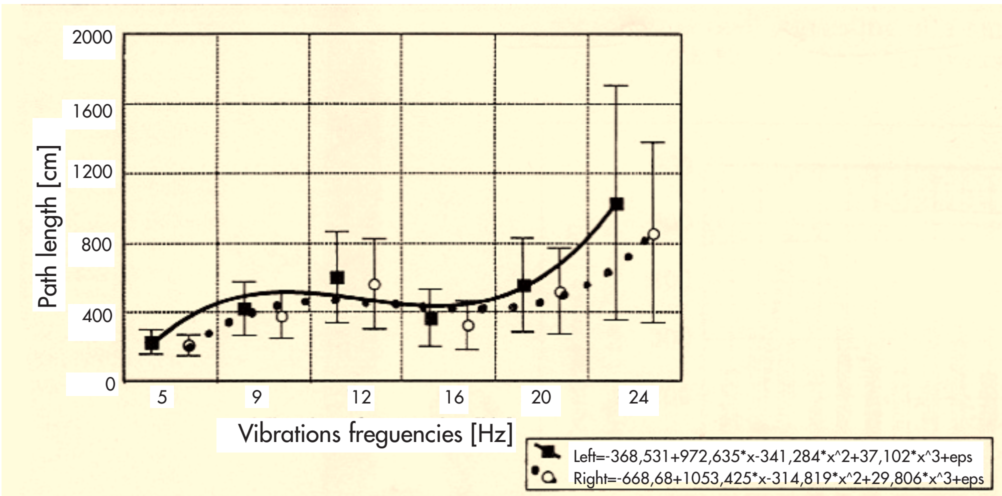

Figure 14: Movement of the upper body with increasing vibration fgequency. Movement increases strongly at approximately 20 Hz (from Mester et al., 1999).

Drerup et al. (1999) studied the relationship between years of exposure to vibration and a number of relevant physical characteristics. No differences were found between a group exposed to vibration and a group that did similar work, but without vibration. There were no differences in characteristics of posture, such as walking, standing and carrying, and no differences in the fluid contents of lumbar intervertebral discs.

Rittweger et al. studied the results of exhaustive whole body vibration, in order to establish the outermost limits of the exercise capacity with this training method (Rittweger et al., 2000). Thirty-seven test subjects twice underwent vibration until exhaustion on different days. The test subjects carried out very slow squats during the vibration. A battery of tests immediately followed exhaustion, including jump height (JH; immediately following exhaustion, 3 times with 5 seconds rest) and maximal contraction (MVC; 2 minutes after exhaustion). The most remarkable result was a decrease in jump height after vibration training, but this decrease disappeared on the last jump (approximately 20 sec after exhaustion). The MVC (2 minutes after exhaustion) was lower following vibration training. On the other hand, the EMG was higher.

The response to the vibration was very individual. The reaction varied greatly from person to person. Some test subjects actually showed a higher jump after vibration training, which is confirmed by the significant correlation between the values measured for JH and MVCm for example, following both vibration training sessions. This has implications for training with vibration. The response to vibration is strongly individual and a training programme should therefore also be individual. The researchers also state that the fatigue after vibration is twofold. In the first place, there is neuromuscular fatigue. The most important reason for this is a poor correlation between lactate after vibration training and loss of jump height on the one hand, and the rapid recovery after 20 seconds on the other hand. The second aspect of fatigue is slower to disappear; the MVC was still lower after 2 minutes. This fatigue may have a more intramuscular cause. The conclusion of the research is that vibration training does not entail an acute risk. All values measured have returned to their original level after 15 minutes.

6. Discussion, conclusions and recommendations

6.1 Force, speed and power

Figures 15 and 16 are respective overviews of the acute and structural effects on force, speed and power which can occur with vibration training. Figures 15 and 16 are the guidelines for this discussion. Both diagrams show the possible parallel effects which can occur. Each effect can have either a positive or a negative influence; there are effects which oppose each other and effects which reinforce each other. It is difficult to assess the resultant of these parallel processes, but this structural approach may nevertheless provide a number of useful suggestions for future study and the use of vibration training in practice.

6.1.1 Acute effects.

Figure 15 shows the acute effects in a diagram. The top two rows refer to vegetative effects, the bottom two to neurological effects. The top row refers to acute intramuscular changes. This effect is almost purely negative (performance reducing), with the exception of a possible improvement in blood flow after a vibration session. Increased concentrations of lactate (Rittweger et al., 2000) and creatine kinase (Mester et al., 1999) were measured in the blood after vibration training sessions, which indicate respectively that muscle fatigue and muscle damage were present. It must be emphasized that loaded vibration training was involved here. Furthermore, the path of the CK concentration is very consistent with the path after an exhausting, but short, physical activity where the stretch shortening cycle (SSC) is applicable (Komi et al., 2000). The eccentric phase in particular in this SSC causes the recovery process to take a specific path: first of all, a sharp fall immediately after exertion followed by a slight recovery, after which a second fall commences that peaks around the second or third day. This peak was also established by Spitzenpfeil et al. (1999) (in Mester et al., 1999) after vibration training. This makes it likely that an SSC also occurs in vibration training; the vibration causes very small stretches in the muscle, although this certainly does not have to be the case in more proximal muscles. It should be noted that both Rittweger et al. and Spitzenpfeil et al. applied the vibration training to traditional weight training, which is to say that the test subjects (or test subject in the case of Spitzenpfeil) did submaximal or maximal contractions on a vibrating plate. It is therefore important whether the vibration training is undergone in a static position, or is actually applied during a dynamic contraction, as indicated in figure 15, under the heading "factors influencing the effect". Intramuscular fatigue is to be expected less quickly in a static position, although this can of course occur when the test subject or athlete has to carry extra weight. In the studies by Bosco et al., the test subjects stood in a static position on a vibrating platform without extra weight, an ideal situation for measuring an acute effect.

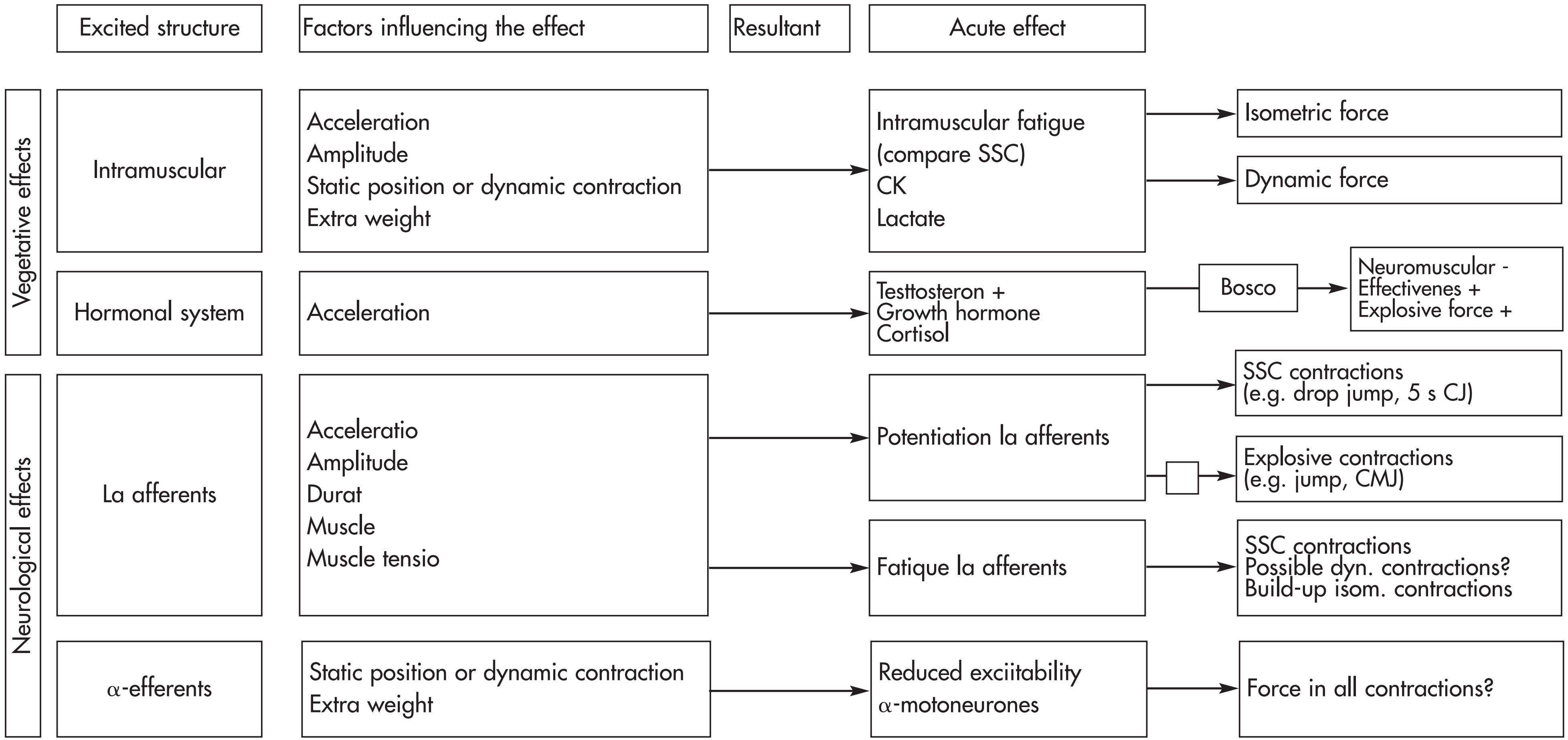

Figure 15. The possible acute effects of vibration training

The acceleration and amplitude also play a role here. A large amplitude means a strong eccentric phase during vibration, while a high acceleration means that a high g-force has to be overcome during that eccentric phase: it is quite probable then that a fatigue process occurs immediately after the vibration session, comparable to the process after an exhaustive SSC. In that case, it is practically impossible to establish any facilitating acute effect (from one of the bottom rows of figure 15), particularly if this acute effect is measured with an isometric contraction. Intramuscular fatigue is more likely to be expressed as a fall in the maximal isometric force than as a fall in the maximal dynamic force. This is also the case after exhaustive vibration training (Rittweger et al., 2001).

The second row refers to the effect established by the Italian researcher Bosco and his research team (Bosco et al., 2000). They discovered that the concentration of testosterone and growth hormone in the blood had increased after vibration training (see chapter 5). According to these researchers, the relevant factor that plays a role in this effect is the acceleration of the vibration training. It was argued that vibration training has the same quality as explosive weight training: increased acceleration. Both forms of training therefore produce a similar effect, i.e. increase of neuromuscular efficiency. The EMG/power ratio is lower after vibration training (acute effect). The question is, however, whether a motor learning effect of this kind can take place within such a short time. The acute hormonal effect of vibration training is an interesting facet of vibration training in any case, and should be taken into account when establishing an acute effect. The high acceleration does, however, constitute an increased risk of intramuscular fatigue. This means that the measurement of the maximal isometric force is not suitable for measuring effect and that the vibration training has to be carried out in a static position without extra weight.

The most prominent impact of vibration training is in the neurological context. The primary afferents of the muscle spindle have traditionally been the most important candidates for experiencing an inhibiting or facilitating effect from the vibrations (the third row from the top in figure 15). The potentiation of the stretch reflex and/or the H-reflex has been established in a number of studies, especially after isometric contractions, but also after SSC contractions (Komi, 2000) (review in Ross et al., 2001). It is hypothetically possible that the positive feedback from Ia afferents undergoes a form of potentiation, which might increase the speed of the development of force during an isometric contraction, but also the build-up of force during an SSC and probably during the first isometric phase of a dynamic contraction. This potentiation has never been established, however. Indeed, Künnemeyer and Schmidtbleicher (1997) actually established a decrease in the H-reflex immediately following a vibration session, and Issurin and Tenenbaum (1999) measured a decrease in power immediately after a vibration session. If there actually was a potentiating effect on the positive feedback from Ia afferents due to vibration training, it would appear to be subject to strict conditions.

One of these conditions could be the acceleration. As stated in chapter 2, the Ia afferents of the muscle spindle respond to changes in the length of the intrafusal muscle fibers. The faster the change takes place, the higher the impulse frequency of the Ia afferents. The response of the Ia afferents is therefore stronger with a high vibration acceleration. This is influenced by the momentary muscle length and the muscle tension. The impulse frequency of the primary afferents is higher when muscle tension is higher, which also applies to muscle tension. In summary, the strongest response from the primary afferents occurs with a high vibration frequency, when the muscles closest to the vibratory source are in a stretched state, while the tension in the muscles is high because a load is being carried (the bodyweight for example). This also plays a major role in the structural effects of vibration training, as will be explained below. The length and tension of mainly the muscles that are close to the vibratory source are important, because more proximal muscles will definitely experience less changes in length, so that Ia afferents fire less strongly or not at all. The amplitude of the vibration is also important in this connection; the 1a activity of more proximal muscle spindles also starts to play a role at greater amplitudes.
However, the most important factor is naturally the duration of the vibration. It has been shown that Ia afferents have a low fatigue threshold (Bongiovanni and Hagbarth, 1990). In the case of prolonged vibration, a possible potentiating effect quickly changes to fatigue of this system, which depends in part on the factors referred to above. Fatigue occurs earlier when there is strong Ia activity, but this activity is necessary – hypothetically – in order to cause a potentiating effect (Ross et al., 2001). The solution, therefore, is very short (repeated sessions of 1 min), intensive Ia activity, as applied in the studies by Bosco. Künnemeyer and Schmidtbleicher used sessions of 2 minutes.
It is remarkable, however, that Bosco et al. established the acute effect of vibration training with contractions in which a relatively minor role is ascribed to Ia feedback, viz. counter movement jumps, dynamic leg press or dynamic flexion of the elbow. More likely choices are drop jumps, for example, or the power build-up during a maximal isometric contraction. These researchers do not therefore speculate in their latest experiments (1999 and 2000) about potentiation of the primary afferents of the muscle spindle, but rather on hormonal effects or a fast motor learning effect, comparable with explosive weight training. Although the stretch reflex therefore has a great potential for facilitation, the results of the experiments refute that this reflex is at the basis of the acute effect of vibration training.

The effect of vibration training on the α efferents themselves is shown at the very bottom of figure 15. This effect can almost be grouped together with the intramuscular effect. When the vibration training is applied during submaximal or maximal contractions, there is a considerable chance that fatigue will develop in the motor units themselves if the duration is long enough. This results in a reduced excitability of α efferents, leading to a decrease in the force and power of all contractions (Gandevia et al., 2001).

Conclusion acute effect

Vibration training has a number of possible potentiating acute effects. The fatiguing effects are dynamic contractions during the vibration training, especially if extra weight is also used. The most probable potentiating effect is acceleration, because this stimulates the production of testosterone and growth hormone, resulting in an increase of neuromuscular effectivity. Research into the acute effect of vibration training should therefore concentrate on vibration with a high acceleration, whereby the vibration is experienced either statically or dynamically, but without extra weight. The path of the possible potentiation of force and power is very important in this connection; whether the effect is permanent or very temporary. This is considered in the following paragraph.

The practical relevance of the acute effect of vibration training is in the field of top sport, or in any case in that branch of sport where performance is of prime importance. An acute potentiating effect is very interesting for athletes who have to deliver a brief, explosive effort. This effect is of little importance, however, to people who exercise for their health. People who exercise for their health benefit from a structural effect, improving physical fitness (an important part of which is strength) by structural methods. This will be examined in the following paragraph.

6.1.2 Structural effects

Figure 16 shows in a diagram the structural effects which could occur with prolonged vibration. In contrast to the acute effect, it is possible from a structural point of view that intramuscular super- compensation occurs after vibration training. The greatest chance that this super-compensation will occur is when sub-maximal or maximal contractions are carried out during the vibration training. The amplitude and acceleration are also important, because these factors determine the (weight of) the eccentric load. Super-compensation naturally only occurs after rest. This rest must be prolonged, especially in the initial phase of vibration training. The first training sessions in particular result in considerable muscle damage, and the recovery process therefore takes a long time. If the time between training sessions is too short, there is a high risk of intramuscular fatigue, just as in a traditional training programme. A guideline is to do vibration training no more than twice a week for the first two weeks, in combination with maximal weight training, in order to prevent intramuscular fatigue (Spitzenpfeil et al., 1999 in: Mester et al., 1999). It should be noted again that scarcely any muscle damage can be established if the vibration training is carried out unloaded. Intramuscular fatigue mainly affects the isometric contraction force; it has much less effect on dynamic contractions. Super- compensation, but fatigue as well, is to be expected less quickly when the vibration training is done in a static posture and without extra weight. Bosco et al. (1998) gave their test group vibration training every day for ten days: the average height on a 5 sec CJ test increased by 12%.

The acute effect of vibration training on hormone production has already been examined extensively in figure 15. The extent to which this effect is also capable of producing structural changes with prolonged vibration training has not been established and would be an interesting subject for further study. It is already being included in a large-scale study at the Catholic University in Leuven.

The most important structural effects are neurological. First of all, researchers like Issurin and Tenenbaum (1994) and Mester et al. (1999) brought about an increase in force by combining vibration training with maximal weight training. This effect is shown in figure 16 in the "Ia afferents" row in the structural effect "motor learning: activation of previously unused motor units". Both researchers put forward the same underlying mechanism in different words. Mester et al. refer to "a need for more motor control" during vibration training, while Issurin and Tenenbaum speculate on an increased excitory volley (originating from Ia afferents) during vibration training, leading to the activation of previously unused motor units. "More motor control" can be put in the same category as increased activity of Ia afferents: there is a greater excitory volley (in comparison with traditional weight training), which could cause an increase in neuromuscular efficiency; e.g. because mechanosensors (primary afferents of the muscle spindle) are able to convert a large volley of impulses more efficiently into the release of neurotransmitter. The question that remains is the following one: does this increased efficiency take place at the level of the motoneurone pool, or at the level of the load compensation through the positive feedback from Ia afferents?

In the first case, vibration training has the potential to increase the force, speed and/or power of all contractions in which the control of muscles is a limiting factor on the force that can be supplied. This therefore applies to maximal, preferably explosive contractions. It is essential in this case that the vibration training provides an extra excitory volley over and above traditional weight training. Maximal weight training at 1 RM together with vibration training produces a higher excitory volley than maximal weight training at 1 RM alone (Issurin et al.), and sub-maximal weight training with vibration training produces an equal excitory volley to maximal weight training alone (study Bayreuth, not yet released by publishers). The first is of particular interest to top athletes pursuing the greatest possible training effect; the second is important for fitness athletes pursuing a substantial effect with modest effort. The percentage of type II fibers may play an important role in the first case. The high excitation threshold of these muscle fibers means they are the most sensitive to an increased excitory volley.

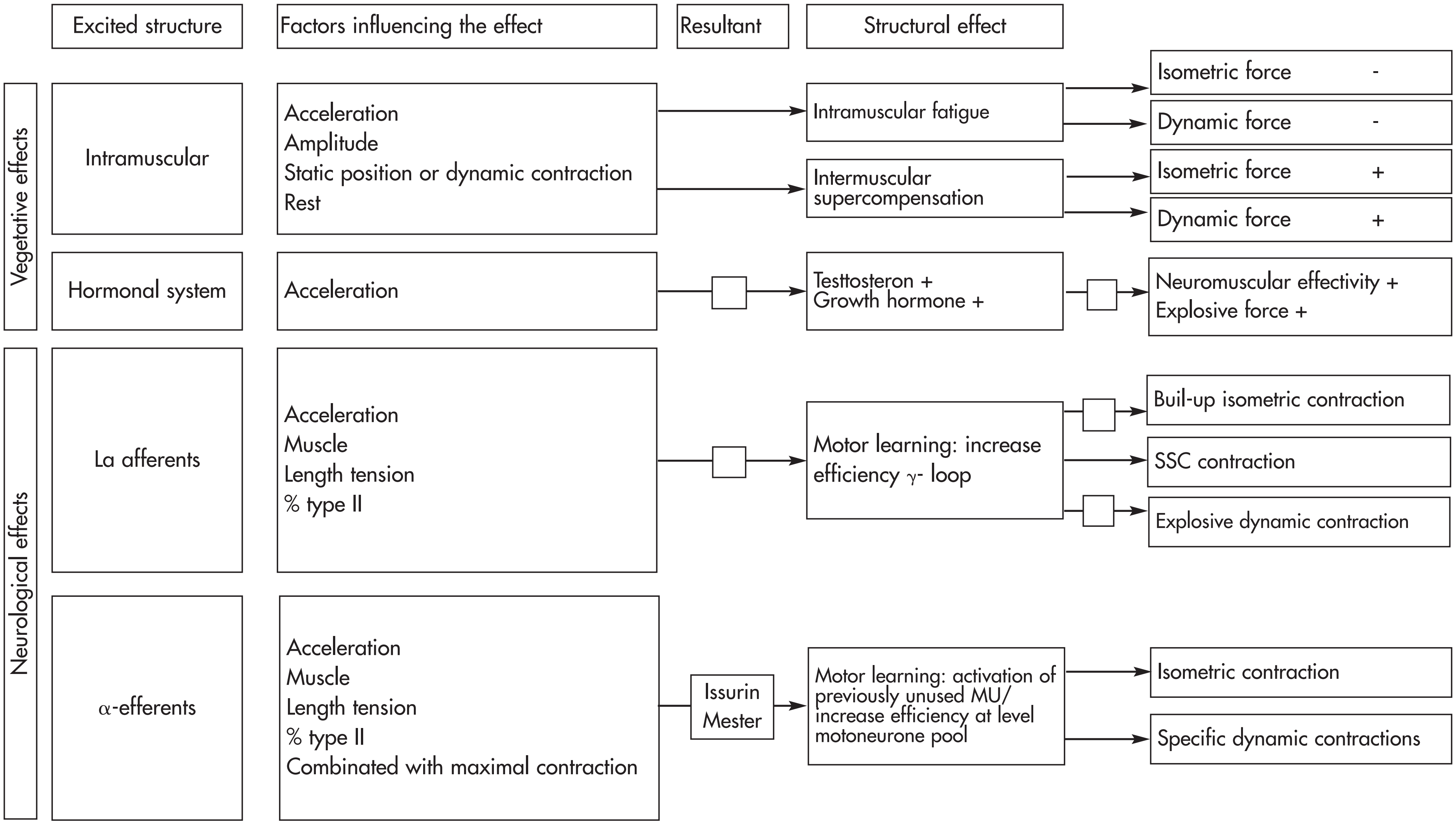

Figure 16. The possible structural effects of vibration training

It is also possible that the effect of vibration training is concentrated at the level of the Ia afferents. It is assumed, after all, that these afferents produce the increased neurological activity during vibration training. The mechanosensors of the muscle spindle are said to be able to convert a large volley of impulses more efficiently into the release of neurotransmitter. Furthermore, it was examined at length in chapter 4 that Ia afferents show a high degree of flexibility: the efficiency of the conversion of mechanical impulses into electric signals can increase strongly under certain circumstances. On the basis of the hypothesis that this feedback could become more efficient as a result of vibration training, the contractions where the SSC is applicable would be most likely to experience a positive influence from this effect. In the case of an SSC, after all, the stretch reflex plays an important role in the build-up of force in the phase in which the eccentric contraction is changed into a concentric one (Komi, 2000). The effect should therefore be established using SSC contractions, like the drop jumps of the 5 sec CJ test. Figure 16 shows a connection with the build-up of isometric contractions. The Ia feedback plays a role in the build-up of force, also in isometric contractions (Hagbarth et al., 1986 and others), and that could be established on the basis of the build-up of force during a fast maximal isometric contraction. The question is, however, whether a contraction of this kind is maximally fast. It would be more obvious to do a dynamic contraction like a CMJ, because test subjects would then be compelled to make an explosive contraction. In addition, the *intention* to make an explosive contraction plays an important role in the motor programme that is being engaged. Behm and Sale (1993) established, for example, that the intention to make a fast movement determines the training effect which occurs, even more than the actual movement made.

Conclusion structural effect

1. The added value of vibration training combined with maximal or sub-maximal weight training is probably an increased excitation volley on the motoneurone pool, in comparison with traditional weight training. This enables vibration training to produce the same effect as maximal weight training without vibration (Universität Bayreuth, 2002, not yet released by publishers). The same mechanism is probably at the basis of an increased progression after vibration training, in comparison with traditional maximal weight training (Issurin et al., 1994 and others). This last effect is only found when maximal contractions at 1 RM are combined with vibration training with a high acceleration. In addition, this form of vibration training has greater potential in athletes with a high percentage of fast muscle fibers.
2. Vibration training either produces a potentiation at the level of the motoneurone pool, or increased efficiency of the Ia afferents in load compensation. In the first case, vibration training provides the potential of increasing the force, speed and/or power in maximal contractions. In the second case, the potential is restricted to contractions in which the Ia feedback could play a role in the build-up of force. These are explosively built-up isometric contractions and contractions in which the SSC occurs.

6.2 Other effects

There are strong indications that vibration training improves bone density. In practice, vibration training can be used to counteract the effects of osteoporosis in that connection. It also appears to be clear that vibration causes a decrease in brief pain sensations. In addition, vibration training affects proprioception. Vibration training has both an acute and a structural effect on the range of motion of joints whose muscles experience vibration. The increase in flexibility with vibration training is suitable for athletes like gymnasts, who need great flexibility in order to practise their sport. The increase of flexibility with vibration training does not reduce the risk of injuries, like a warming-up does, for example.

6.3 Possible harmful effects

Research has shown that prolonged exposure to vibration also does not necessarily lead to damage. Nevertheless, vibration training under expert supervision is preferable to solitary training, because it has been shown that the response to vibration training varies strongly per individual. Individual supervision appears to be strongly advisable from this point of view as well.

6.4 Recommendations

Broadly speaking, vibration training has two effects: an acute effect and a structural effect. The structural effect is the most relevant. This structural effect can in turn be split up into two categories. The first is the more important for competitive athletes and has received the most attention from scientific researchers in recent years: the addition of vibration training to maximal weight training in order to produce a greater effect than maximal weight training alone. The second category is of more interest to the recreational athlete and patients in rehabilitation: vibration training carried out statically or with sub-maximal contractions like knee flexions. What makes this form so interesting is that the same effect can be achieved with a modest training effort as with a major effort like maximal weight training. In addition, it is not so very interesting whether this training effect is greater or smaller than what can be achieved with traditional weight training, because both forms are completely different where a number of characteristics are concerned. It is not the effect which is relevant, but whether the athlete is willing or able to carry out the training.

The following is a very important consideration. The neurological activity during whole body vibration is assumed to originate in the Ia afferents, which give negative feedback on the basis of the change in length of the muscles. It should be noted that this is an assumption. As was already stated in paragraph 2.5, it has been established or modelled in recent studies that not only excitation of efferents can take place through negative feedback based on the change of muscle length, but also excitation of the host muscle through positive feedback of muscle tension, detected by Golgi tendon organs. The implication of this is that research results must be interpreted with the greatest of care. The fact is that it can no longer be stated with certainty which neurological structures are excited by whole body vibration. Furthermore, it is also unclear in which contractions these structures (the γ loop for example) are involved in the build-up of force.

In other words, there are still too many unknowns at present to be able to fully expose the underlying mechanisms of whole body vibration. This means that the emphasis on the acquisition of knowledge regarding vibration is concentrated on the practical situation. It is extremely important that experience with vibration training be documented; the creation of a body of knowledge depends on this to a great extent. It is essential, therefore, that vibration training is supervised by experts who are building up a body of knowledge on the pressure of vibration training in relation to the exercise capacity of various athletes and rehabilitating patients. Training under expert supervision guarantees a careful build-up and prevents experimentation on the part of the athlete /rehabilitating patient.

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Power Plate International
Jan van Gentstraat 160
1171 GP Badhoevedorp
The Netherlands
Tel.: +31(0)20-6401670
Fax.: +31(0)20-4450478
E-mail.: info@power-plate.com
Website: www.power-plate.com

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