In numerous sports and sport events performance is, to a great extent, determined by the level of speed-strength. An optimal preparation (warm-up) is necessary to achieve the highest possible realization of speed-strength in training and competition. Some top international athletes are said to have produced the highest speed and speed-strength performances immediately after having performed a few Maximal Voluntary Contractions (MVCs). However, as yet no target-oriented and systematic studies of MVCs, as an element of warm-up programmes, have been conducted. Therefore the focus of the following study is on the following questions: (1) To what extent can the short-term potentiation of speed-strength induced by MVCs be considered as a general effect? (2) Can effects of post-tetanic potentiation be triggered in human beings by MVCs? (3) To what extent is there a connection between possible short-term increases in speed-strength and neuronal effects of post-tetanic potentiation? The results of two complex training experiments show that MVCs carried out during the warm-up can really lead to a considerable increase in speed-strength performances of the lower extremities in all athletics sprint and jumping events and of the upper extremities in the shot put and the throws.

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Prof. Dr. Dietmar Schmidtbleicher occupies the chair of sport science at the Institute of Sport Science of the University of Frankfurt/Main. The focus of his work is performance diagnosis. Translated from the original German by Jürgen Schiffer
performance alterations are most probably caused by neuronal factors of speed-strength behaviour.

1.3 Post-tetanic potentiation as an attempt at an explanation

During MVCs the activated motor units are stimulated with very high tetanic stimulus frequencies of more than 100Hz. It has been demonstrated in animal experiments that, after tetanic stimulations, the effectiveness of stimulus transmittance in excitatory synaptic junctions between nervous cells can remain increased for several minutes (HENNEMANN/MENDELL 1981, LÜSCHER et al. 1983, HUTTON 1989, GOSSARD et al. 1994). Post-tetanic potentiation (PTP) expresses itself in the form of a better input-output relationship: After tetanization, an identical pre-synaptic stimulation leads to higher excitatory post-synaptic potentials (EPSPs). If the effects of neuronal PTP were to be triggered by MVCs in human beings, an improvement in particular of the voluntary neuromuscular activation could be expected. However, in 1989 HUTTON indicated that a neuronal PTP, under the condition of a natural neuronal activation, had not yet been convincingly shown in human beings.

1.4 Formulation of the questions

The focus of the study is on the following questions:

1) To what extent can the short-term potentiation of speed-strength by MVCs be considered as a general effect?

2) Can neuronal effects of post-tetanic potentiation be triggered in human beings by MVCs?

3) To what extent is there a correspondence between possible short-term increases in speed-strength and neuronal effects of post-tetanic potentiation?

For the analysis and subsequent transfer of the results to practice, a detailed knowledge of the investigation method is necessary. Therefore, this presentation starts with the description of the method of the investigation. After this, based on the results of the experiment, it is shown that, in most trained speed-strength athletes, MVCs have indeed a short-term potentiating effect on performance and that this phenomenon can be attributed to the neuronal PTP. Finally the conclusions to be derived for training and competition will be described.

2 Method of the investigation

Two complex investigations were carried out. In the first study, speed-strength performances of the upper and lower extremities, prior to and immediately after MVCs, were measured and compared. The test exercises used were the bench press, using a guided barbell, and vertical jumps in the form of countermovement jumps (CMJs) and drop jumps (DJs). The objective of the second investigation was the evaluation of parameters of neuromuscular activation, prior to and after MVCs, and the comparison of their temporal course with that of the gross motor explosive-strength output. To this end, the maximum H-reflexes at the triceps surae muscle and the explosive force were measured during voluntary isometric plantar flexions.

2.1 Subject samples

Table 1 gives an overview of the partial samples of the individual experiments.

First study

36 athletes served as the subjects for the first study. 34 athletes participated in both the bench press and the jumping tests. All athletes were competitive speed-strength athletes of regional (n = 22; 61%) or national to international level (n = 14; 39%). Seventeen subjects were competitors...
in the sprints, jumps and throws of track and field athletics, while 19 were game players, combat or power sport athletes. Table 2 gives data about the subjects and the control performances of this sample. Furthermore, 12 competitive female athletes of different speed-strength sports took part in the bench press, and 11 took part in the CMJ test.

**Second study**

For the second study, the H-reflex experiments were first of all conducted with seven sport students, who did not do any strength training, and then with ten athletes who had taken part in the first study. Eight of the trained competitive athletes participated again in the measurement of the time course of explosive force behaviour during voluntary plantar flexion. In terms of the personal data and control performances, these partial samples correspond with the subject samples in the first study.

### 2.2 Feature sample

**Bench press**

In the starting position the subjects lay on their backs on a table adjustable for height. The elbows (90° angle) had contact with the table and only the proximal balls of the thumb were in contact with the barbell. The athletes were asked to push the guided barbell (16.9kg) upward as explosively and fast as possible. Using a contact-free photoelectric measuring system (FICHE et al. 1994), the time for every 0.4cm of the movement of the barbell up to 40cm was recorded, with a temporal resolution of 1/50000sec. From the data obtained the force-time relation could be derived.

The treatment MVCs were performed in the form of bench press trials, with additional loads and using the same movement.

**Vertical jump**

The CMJs and DJs were performed on a KISTLER dynamometric platform. During the whole movement the subjects held their hands at their waists. Flight height was measured using the flight-time method. In addition the contact time was measured during the DJs from a drop height of 32cm. In each case the mean values of 8 jumps were used for evaluation.

Unilateral, isometric leg-press trials of 5sec duration, at a hip angle of 95° and a knee angle of 120°, were used as MVCs.

**H-reflex**

The tibial nerve was stimulated transcutaneously in the hollow of the knee. The excitation potential travels via the efferent paths (alpha-motoaxons) directly to the neuromotor end-plate in the triceps surae muscle, and, at the same time, via afferent fibres (mainly la-fibres) to the spinal cord. There, like the signal of the stretch reflex, the stimulus is transferred monosynaptically to alpha-motoneurons and is transmitted again in the motoaxons to the neuromotor end-plate in the triceps surae muscle. The individual stimulus triggers 2 separate responses at the neuromotor end-plate, the summary action potentials of which can be derived electromyographically, the direct muscle response after about 5msec (M-wave) and the H-reflex response (H-wave) after about 30msec (Figure 1).

The focus was on the peak-to-peak amplitude of the H-wave, which is a reflection of the number of activated motor units. If the H-amplitude varies with constant stimulation, this is an indication of a changed activation behaviour, which is caused by a modification of the synaptic efficiency of the stimulus transfer to the alpha-motoneuron pool.

During the H-reflex measurements, the subjects lay, relaxed, on their backs on a gymnastic mat. The heel and achilles tendon of the investigated leg were positioned on a padded box which was 22cm high.
At an ankle joint angle of 90°, the sole had contact with a KISTLER platform. Padded supports were positioned in the area of the head and shoulders.

For each athlete, stimulation was adjusted in such a way that, under control conditions (prior to MVCs), the highest possible H-reflex activation in the lateral gastrocnemius muscle (MGL) was guaranteed. With this stimulus configuration, the H-response could be recorded in the 'slower' soleus muscle (SOL) of 9 subjects simultaneously. In all cases the mean H-amplitude of 12 trials was the test parameter.

The MVCs consisted of unilateral, isometric plantar flexions of 5 sec duration in the same position.

Explosive force plantar flexion
The athletes were adjusted into the same position as during the H-reflex experiment. They were asked to exert force, as explosively and as fast as possible, onto the platform with the ball of the foot. The steepest rise in force average movement of over 30 m/sec of each trial was used for evaluation. The mean value of 3 trials served as the test parameter. The treatment MVCs were carried out analogously to the H-reflex trial.

Table 3 indicates the reliability found for each of the features measured in the retest procedure.

2.3 Experimental design and procedure of the experiment
All test units were organised according to the pattern 'test - treatment MVCs - test'.

Table 4: Configurations of the treatments used

<table>
<thead>
<tr>
<th>Configuration of treatments used</th>
<th>Number and intensity of treatment-contractions</th>
<th>Rest interval between treatment-contractions</th>
<th>Rest interval between treatment-contr. and post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>First investigation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bench press</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TU 1</td>
<td>34</td>
<td>2 × 1 × ≥100% (2)</td>
<td>5 min</td>
</tr>
<tr>
<td>TU 2</td>
<td>33</td>
<td>3 × 1 × ≥100%</td>
<td>5 min</td>
</tr>
<tr>
<td>TU 3</td>
<td>32</td>
<td>1 × 3 × 90%</td>
<td>-</td>
</tr>
<tr>
<td>TU 4</td>
<td>19</td>
<td>5 × 5s × ≥100% (4)</td>
<td>1 min</td>
</tr>
<tr>
<td>TU 5</td>
<td>16</td>
<td>1 × 1 × ≥100%</td>
<td>-</td>
</tr>
<tr>
<td>Vertical jump</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TU 1</td>
<td>34</td>
<td>3 × 5s MVC</td>
<td>5 min</td>
</tr>
<tr>
<td>TU 2</td>
<td>32</td>
<td>3 × 5s MVC</td>
<td>5 min</td>
</tr>
<tr>
<td>TU 3</td>
<td>28</td>
<td>3 × 5s MVC</td>
<td>5 min</td>
</tr>
<tr>
<td>TU 4</td>
<td>16</td>
<td>3 × 5s MVC</td>
<td>5 min</td>
</tr>
<tr>
<td>TU 5</td>
<td>16</td>
<td>5 × 5s MVC</td>
<td>5 min</td>
</tr>
<tr>
<td><strong>Second investigation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H-reflex</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fexp planatarflexion</td>
<td>17</td>
<td>5 × 5s MVC</td>
<td>1 min</td>
</tr>
<tr>
<td>Fexp plantatarflexion</td>
<td>8</td>
<td>5 × 5s MVC</td>
<td>1 min</td>
</tr>
</tbody>
</table>

Each unit was introduced by a standardized warm-up programme, which included 10 min jogging and 10 min stretching exercises. Furthermore, the speed-strength tests were always preceded by 9 trials of moderate to maximum intensity. Prior to the MVCs there were always 2 submaximal trials. Between the MVCs and the posttest no trial was allowed.

The tests were conducted as a series of individual trials. Each bench press series consisted of 5 trials, with a rest interval of 30 sec each, the jump test had 8 trials, with a rest interval of 20 sec. The H-reflex was always triggered 12 times, with a rest interval of 5 sec, and the measurement of the explosive force of plantar flexions was always taken 3 times, with a rest interval of 30 sec. In the first investigation (bench press, vertical jump) one test series was measured each, prior to and after the MVCs. In the second investigation (H-reflex, explosive force during plantar flexion) a
control series was also carried out prior to the MVCs. After this the data produced were recorded every second minute, up to 13 min after the MVCs.

In the case of the first investigation, 5 test units were carried out for each speed-strength test of the upper and lower extremities, with different stimulus configurations (Table 4). The stimulus configuration includes the stimulus volume, intensity and density, and also the time interval between treatment and post-test. The different combinations of these characteristics led to complex treatments of different severity. It was expected that the systematic variation of individual variables of the stimulus configuration would produce suggestions for training and competition, as well as the identification of possible explanations. For the experiments of the second investigation the most demanding treatment was maintained.

3 Results
3.1 First investigation
Bench press
Figure 2 presents the derived force-time courses of the bench press tests, prior to and after

![Figure 2: Bench press test – Course of the force-time relationship before and after different treatments](image-url)
Different stimulus configurations – arranged according to the severity of the treatment.

The first test unit included 2 control series with a rest interval of 3 min. This arrangement allows the assessment of the effect of a 'zero treatment' of the 3 min rest interval: In the second control series, there was a reduced performance, especially in the dynamically produced force maximum (p < .05).

The execution of sub-MVCs (3x90%) led to practically no change of the rise in force. In the area of the maximum force, slight improvements could be identified. However, the effects of these improvements are hardly worth mentioning (< 1%) and not significant (p > .05).

All MVC-configurations showed significantly positive effects on the rise in force, i.e. explosive force (all p < 0.5). The greatest effects were produced by 1 to 3 MVCs using a low stimulus density (5 min rest interval).

In the area of the dynamically achieved force maximum there was a slight reduction of performance (up to about 1%) with the more rigorous stimulus configurations (3 and 5 MVCs). However, in all MVC-units there was a pronounced shift to the left of the whole force-time curve. This means that, even with 5 MVCs, the gains in explosive force – related to the time needed for the movement distance – overcompensated for the losses in the area of the force maximum. After this most rigorous treatment, as also after 3 MVCs, the movement velocity was higher than under control conditions up to 180 msec of movement time. After 1 and 2 maximum contractions this was the case at every point of the movement.

The bench press tests of the female athletes led to similar results.

**Vertical jump**

In the CMJ, 2 control series, with a rest interval of 3 min, were also carried out during the first unit. In the first series there was an intraserial 'positive staircase' from the first to the eighth jump (Figure 3). However, after the 3 minute rest interval this 'positive staircase' did not continue; the group of athletes started and finished the second series of jumps at the same level as the first one. After the 3 min rest interval the athletes reached heights which were, on average, 0.2 cm lower. However, 3 to 5 minutes 20 seconds after 3 MVCs they jumped on average 1.4 cm higher (3.3%, p < .001). Furthermore, the intraserial rise in performance was steeper (p < .05).

A comparable effect was also observed during the DJ from a drop height of 32 cm. With almost unchanged contact times, the significantly increased flight heights give evidence of the short-time improvement of the neuromuscular performance output (p < .05, Figure 4). During the DJ the intraserial performance increase after the maximal contractions was steeper, too (p < .05).

However, such a short-term potentiation of speed-strength must not be expected under all circumstances. On the days prior to the different test units, some athletes had performed high

![Figure 3: CMJ heights in 2 control series with a 3 min interval (1st and 2nd series) and after 3 MVCs (post-MVCs) Group mean values.](image)
Figure 4: Flight heights (h) and contact times (t) in drop jumps before (broken line) and after 3 MVCs (unbroken line) Group mean values.

anaerobic-lactacid loads during their event-specific training (e.g. tempo runs). These subjects showed a reduction, or even inversion, of the potentiating MVC-effect. For example, in the second test unit, these subjects (n = 10) showed, on average, a performance reduction of 3.1% (Figure 5).

Table 5 gives an overview of the results of the jumping sessions with different treatments. This table shows, for example, that the different MVC-configurations used led to comparable improvements in performance during the CMJ.

Figure 5: MVC-induced changes of CMJ height with and without high anaerobic-lactacid loads on the previous day Group mean values. See text for further explanations.
Table 5: Jumping performances prior to and after different MVC configurations

Top: Without anaerobic-lactacid load on the previous day. Below this: With anaerobic-lactacid load on the previous day. Bottom: Results of the female athletes (ATHLI).

In each case mean values of 8 jumps with a 20sec rest interval, group mean values.

- p>.05; * p<.05; ** p<.01; *** p<.001

<table>
<thead>
<tr>
<th>Feature</th>
<th>n</th>
<th>pre</th>
<th>post</th>
<th>Diff</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without lact. load on the previous day</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 MVCs, 5min, 3min h</td>
<td>24</td>
<td>43.2</td>
<td>45.1</td>
<td>4.4%</td>
<td>***</td>
</tr>
<tr>
<td>3 MVCs, 5min, 3min h</td>
<td>22</td>
<td>43.6</td>
<td>44.7</td>
<td>2.6%</td>
<td>***</td>
</tr>
<tr>
<td>3 MVCs, 5min, 1min h</td>
<td>24</td>
<td>43.0</td>
<td>44.5</td>
<td>3.5%</td>
<td>***</td>
</tr>
<tr>
<td>5 MVCs, 1min, 3min h</td>
<td>13</td>
<td>42.6</td>
<td>44.6</td>
<td>2.7%</td>
<td>*</td>
</tr>
<tr>
<td>3 MVCs, 5min, 3min h</td>
<td>11</td>
<td>33.9</td>
<td>35.3</td>
<td>1.7%</td>
<td>**</td>
</tr>
<tr>
<td>(DJ) t&lt;sub&gt;c&lt;/sub&gt; h</td>
<td>11</td>
<td>165.3</td>
<td>161.7</td>
<td>-2.5%</td>
<td>-</td>
</tr>
<tr>
<td>RPI</td>
<td>11</td>
<td>207.7</td>
<td>229.5</td>
<td>9.7%</td>
<td>-</td>
</tr>
<tr>
<td>With lact. load on the previous day</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 MVCs, 5min, 3min h</td>
<td>10</td>
<td>42.3</td>
<td>42.5</td>
<td>2.2%</td>
<td>-</td>
</tr>
<tr>
<td>3 MVCs, 5min, 3min h</td>
<td>10</td>
<td>42.3</td>
<td>41.0</td>
<td>-1.1%</td>
<td>-</td>
</tr>
<tr>
<td>3 MVCs, 5min, 1min h</td>
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<td>45.9</td>
<td>46.7</td>
<td>1.7%</td>
<td>-</td>
</tr>
<tr>
<td>5 MVCs, 1min, 3min h</td>
<td>3</td>
<td>44.9</td>
<td>45.6</td>
<td>1.7%</td>
<td>-</td>
</tr>
<tr>
<td>3 MVCs, 5min, 3min h</td>
<td>5</td>
<td>36.2</td>
<td>36.5</td>
<td>1.5%</td>
<td>-</td>
</tr>
<tr>
<td>(DJ) t&lt;sub&gt;c&lt;/sub&gt; h</td>
<td>5</td>
<td>161.1</td>
<td>165.4</td>
<td>4.7%</td>
<td>-</td>
</tr>
<tr>
<td>RPI</td>
<td>5</td>
<td>226.0</td>
<td>223.8</td>
<td>-1.0%</td>
<td>-</td>
</tr>
<tr>
<td>ATHLI without lact. load on the previous day</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 MVCs, 5min, 3min h</td>
<td>11</td>
<td>32.7</td>
<td>33.7</td>
<td>2.5%</td>
<td>-</td>
</tr>
</tbody>
</table>

SC = stimulus configuration: MVC-number, rest interval between MVCs, rest interval between MVCs and post-test; Diff = difference values calculated from the test/control performance ratio; h = height; t<sub>c</sub> = contact time; RPI = reactive performance index h/1000; lact. load = anaerobic-lactacid load; ATHLI = female athletes

3.2 Second investigation

In this section, we present the records of the H-reflex amplitudes and the explosive force of voluntary plantar flexions for each individual measuring minute, together with the highest level of these features after the MVCs (PeakH, PeakFexp) and the time of their occurrence (tPeakH, tPeakFexp). For this presentation, the measuring data of each subject were standardized (control value = 1).

H-reflex

Figure 6 shows the EMGs of one athlete; these are typical of the behaviour of the whole group.

Figure 6: Typical EMGs of H-amplitudes (H) of the lateral gastrocnemius muscle (MGL) and soleus muscle (SOL) under control conditions (pre-MVCs), 0 to 60sec after and 10 to 11min after 5 MVCs

Hurdler, German Championships finalist.
Immediately after the treatment-contractions, the H-amplitude of the gastrocnemius muscle (MGL) was considerably suppressed (post-tetanic depression, PTD). The restoration exceeded the control level by far. The potentiation between 4 and 11 minutes was statistically significant (p < .05, Figure 7).

The time of the athletes' highest reflex responses shows considerable interindividual variation: tPeakH = 8.7 ± 3.6 min (range: 2.5 to 12.5 minutes). In order to test the reproducibility of the H-time course, the experiment was repeated with 5 athletes. The retest reliability coefficient of $r_{tt} = .91$ is an indication of a high intraindividual
Figure 9: Time course of the H-amplitude of the lateral gastrocnemius muscle before and after 5 MVCs with speed-strength athletes (ATHL) and sport students (SPST). Group mean values. Group differences: * p<.05; ** p<.01; *** p<.001.

correspondence of the two series of measurements.

The time course of the H-amplitude in the soleus muscle (SOL) was similar to that of the MGL (r = .84, Figure 8). However, potentiation in SOL was lower (PeakH-MGL = 1.32 ± .21 - 32% potentiation; PeakH-SOL = 1.20 ± .20 - 20% potentiation; difference: p < .05) and of shorter duration (tPeakH-MGL = 8.7 ± 3.6 min; tPeakH-SOL = 5.6 ± 4.0min). There were also differences of potentiation behaviour between the two groups of speed-strength athletes and sport students:

The trained athletes showed a significantly higher

Figure 10: Time course of the explosive force (Fexp) with voluntary isometric plantar flexions before and after 5 MVCs. Group mean values. Difference from control value: * p<.05; ** p<.01.
Determination of the onset of the effect of post-tetanic potentiation in the MGL (PeakH-athletes = 1.42 ± .17 - 42% potentiation; Peak H-sport students = 1.11 ± .25 - 11% potentiation; difference p < .05), and the potentiation had a longer lasting effect (tPeakH-athletes = 8.1 ± 3.6min; tPeakH-sport students = 5.9 ± 3.8min; difference, p < .05, Figure 9). Comparable tendencies could be seen in SOL.

Explosive force plantar flexion

During voluntary plantar flexions, the athletes also initially showed a temporary reduction of explosive force after the MVCs. The steepness of the increase in force reached the control level once again, on average between 2 and 3min, and was significantly higher between 4 and 13min (p < .05, Figure 10). PeakFexp was 1.19 ± 14 (19% potentiation). The times of the highest explosive force performances were scattered between 4.5 and 12.5min, and tPeakFexp was 9.0 ± 3.5min. This means that explosive force is also characterized by a high interindividual variability of the time course.

Correspondence of the time courses of H-reflex and explosive force

There was a correspondence of \( r = 0.89 \) between the times of the highest expression of the H-reflex amplitude and the explosive force of voluntary plantar flexions (tPeakH-MGL and tPeakFexp). The athletes who had an early peak in the H-reflex also reached their best values of explosive force early after the MVCs, while those with a late maximum H-potentiation also reached their maximum performance in explosive force late (Figure 11).

In order to test whether there was a correspondence of the total time courses of the two features beyond the time points of maximum expression, the correlation coefficients between the two series of measurements of each athlete were z-transformed according to Fisher, their mean value was calculated and then the correlation coefficient was retransformed. The mean correlation coefficient of the time courses of the H-amplitude of the MGL and the explosive force was \( r = 0.90 \). The reflex amplitude of SOL also varied with the explosive force increase, but the correlation was not so close \( (r = 0.75) \).

4 Discussion

On the basis of the results presented it is evident that the use of a few MVCs is sufficient to cause a short-term increase in the speed-strength performances of the upper and lower extremities. The positive effects on performance express themselves mainly in the steepness of the rise in force, i.e. in explosive force. Furthermore, it was demonstrated that, with successful athletes, MVCs can trigger neuronal effects of post-tetanic potentiation at the spinal-segmental level and that the short-term increase in explosive force can be attributed to an improved neuromuscular activation due to the neuronal PTP effects.

The opening-up of neuromuscular activation reserves

The accumulated action potentials at the neuromotor end-plates are reflected in the H-reflex amplitude. The increase in amplitude means that more motor units were activated than before the execution of the MVCs, with the stimulation maintained constant.

With voluntary motor actions it is not possible to recruit all motor units with maximum frequency; there remains an autonomously protected activation reserve. Numerous synapses project onto each alpha-motoneuron. The action potential is transferred and transmitted only if the simultaneous release of transmitters at a sufficient number of pre-synaptic terminals coincides with an adequate post-synaptic receptor sensibility. In conjunction with a transient post-tetanic calcium accumulation in the pre- and post-synaptic cells, the probability of transmitter release for each individual synaptic terminal remains as increased as the post-synaptic receptor sensibility (Lüscher et al. 1983, Eccles 1983, Mendell 1984, Fisher/Johnston 1990, Gossard et al. 1994).

Within the fragment of the activation reserve, large FT-units are overrepresented. Following Henneman's 'size principle' (Henneman et al. 1965, Freund et al. 1975) the motor units which are additionally activated following the MVCs should always be the next largest after the units already recruited.

This means that the MVCs lead to a transient opening-up of activation reserves, especially in the area of the large, 'fast' FT units.

PTP in 'fast' and 'slow' muscles

The ascertained differences of the effects of PTP between MGL and SOL correspond with the positive relationship between potentiation and the size of the motor units. This has been found in numerous animal experiments. In cats correlations have been found between the amplitudes of excitatory post-synaptic potentials of la-alpha-connections (la-EPSP-amplitudes), as indicators of cell size (large units show small EPSPs) and the height of the potentiation from \( r = -0.66 \) to \( r = -0.86 \) (Lüscher et al. 1983, Collins et al. 1984, 1986, Koerber/Mendell 1991). The different potentiation behaviour of the speed-strength athletes, as compared to sports students, can presumably also be interpreted in this context.
Stimulus configuration

Unlike the treatments of maximum contractions, submaximum contractions (3×90%) could not trigger any considerable effect on explosive force. This cannot be attributed to stimulus volume, because MVCs led to considerable increases in explosive force, both with a lower and a higher volume. The differences might rather be caused by the stimulus intensity itself. In general, fewer motor units are activated with sub-MVCs, and, to be precise, especially fewer FT-units. Besides, the innervation of the recruited motoneurons takes place at a stimulus frequency which is lower than in the case of maximum contractions. In various basic investigations it has become clear that the

![Figure 11: Correspondence of the time courses of the explosive force of voluntary isometric plantar flexions (Fexp) and the H-amplitude of the lateral gastrocnemius muscle (H) before and after 5 MVCs](image-url)
extent of PTP is, among other factors, determined by the stimulus frequency of the treatment (e.g. Collins et al. 1986). Davis et al. (1985) found that, in mammals, there is a threshold frequency for the induction of PTP of around 100Hz.

Apart from stimulus frequency, PTP is also dependent on the volume or duration of the treatment-stimulation (Luscher et al. 1983, Collins et al. 1984, Iriki et al. 1990). This is presumably one of the reasons for the fact that the execution of the speed-strength series alone had no positive effect on performance over minutes.

It can be concluded that a high proportion of FT-units and maximum stimulus intensity (at 100%) and a considerable stimulus duration (several seconds) are necessary to trigger off the neuronal PTP effects induced by voluntary treatment-contractions.

Potentiation and fatigue effects

As far as the upper extremities are concerned, positive effects were to be seen in the rise in force in all cases within the MVC-treatments. However, with increasing severity of stimulus configuration, there were also (slight) reductions in the force maximum. While the behaviour of explosive force can, to a great extent, be explained by the changes of neuromuscular activation, variations of the dynamically achieved force maximum are primarily dependent on the muscle component. Thus, speed-strength performances of the arms, following especially rigorous MVC-treatments, can be considered as the net result of mainly neuronal potentiation and the effect of mainly muscular fatigue, together with their time course. In the jumping tests such obvious differences of the various treatments were not found. For the lower extremity, fewer variants of MVC-configurations were used, and also the speed-strength behaviour was measured in a less differentiated way than during the bench press test. Furthermore, it can be assumed that, because of the lower proportion of FT-fibres, the lower extremities are less sensitive than the upper extremities to both potentiation and the effect of fatigue.

Anaerobic-lactacid exercise on the previous day

High anaerobic loads on the previous day lead to a reduction of the intraserial increase in performance during control and test series, and especially to a reduction, or even inversion, of the MVC-effect on speed-strength performance. 24 hours after such training or competition loads, one must expect not only long-lasting impairments of energy metabolism but also, and especially, a reduced excitability of the motoneurons. This can be caused both by permanent modifications of the magnesium and sodium concentrations, together with enzymatic changes and by structural impairments of the nuclei of motoneurons (e.g. Bigland-Ritchie 1981, Keul et al. 1984, Edgerton/Hutton 1988, Pollmann/Williamczik 1991). According to a personal communication from Komi (1995), on the days after extreme loads a close relationship between the variation of the excitability of the alpha-motoneurons and the CK value can be observed. As an effect of high anaerobic-lactacid loads, it can be assumed, among other factors, that, on the following day, the demands made on the stimulus configuration for neuronal PTP induction (e.g. highest FT-activation and highest possible stimulus frequency over seconds) cannot be sufficiently fulfilled.

5 Conclusions for training and competition

From the results presented, one may draw practical conclusions that are highly relevant to the effectiveness and efficiency of methods of training and competition.

Validity for different groups of athletes

The speed-strength potentiation has been verified for the upper and lower extremities in different groups of male and female athletes. It is to a great extent independent of personal characteristics (age, gender), training (volume, training age and predominant length of series in maximal-strength training, complete training volume, sport) and the athlete's performance (speed-strength and maximum strength of the legs and arms). This indicates a high general validity of the effects within populations of trained speed-strength athletes.

In pilot studies it has been shown that the use of a few MVCs is also effective in top-level international sport. 3x3 MVCs performed by 3 A-squad bobsledgers led to an average increase in CMJ performance of 2.7%. The bobsledgers made use of the short-term MVC-effect in their top competition and won the World Championship title in 1995. In event-specific tests in athletics, the efficiency of maximum contractions was also evident in athletes of the national team: In the one-legged 5-jump test 5 A- and B-squad athletes (decathlon, sprint) achieved, on average, 1.8% longer distances after 3x3 MVCs (squats). Following 3x3 MVCs (bench press), the performances of 5 decathletes (4 B-squad athletes, 1 member of the Swedish national team), in the throw for distance with a 2kg medicine ball from a kneeling position, improved, on average, by 4.2% (in each case mean values of 5 trials).
Effectiveness for short time patterns

The positive effects on performance can be seen mainly in the rise in force. Explosive force is the more significant the shorter the available time for the development of speed-strength. In general, performances with an impulse duration of up to about 170 msec are determined mainly by the level of explosive force. These performances are, for example, speed-strength efforts of the lower extremities in all sprint and jumping events, and of the upper extremities in the shot put and the throws. The same applies to sprints, jumps, throws and strikes in other sports.

Use during competition and training

The short-term MVC-effects can be used to improve performance during competition by integrating the MVCs into the warm-up programme. Furthermore, athletes can profit from the effect of MVCs in training, too. If, during specific speed-strength training, maximum performances are achieved under conditions of improved neuromuscular activation (after MVCs), particularly high adaptations are to be expected and more FT-units are recruited by the training stimulus. Advances in technique training can also be promoted, especially if the MVCs are used selectively in technique-oriented muscle groups.

Optimal stimulus configuration

It should be emphasized that the short-term increase in neuromuscular activation and explosive force can be expected only if the treatment-contractions are performed using a maximum stimulus intensity (i.e. with an additional load of \( \geq 100\% \) 1 RM and explosive start of the contraction) and the necessary duration of the stimulus (several seconds).

From the comparison of different stimulus configurations it also emerged that, during CMJs treatments of different rigorosity, 3 to 5 MVCs had comparable effects. In the bench press 1, 2 and 3 MVCs led to similarly high increases in explosive force, while the most exacting stimulus configurations (3 and 5 MVCs) led to losses of performance with regard to the force maximum. For the majority of athletes, 3 MVCs (possibly also 1 or 2) obviously provide sufficient potentiation stimuli in the lower extremities, while, in the upper extremities of most athletes, 1 or 2 MVCs lead to maximum increases in explosive force, without impairment of the dynamically achieved force maximum.

Time course of potentiation

With individual athletes (n = 7), the observation of the H-reflex amplitude was continued longer than the usual period of time. PTP effects could be registered up to more than 20 min. The potentiation of neuromuscular activation and explosive force is characterized by a high interindividual variability of the time course. It must be concluded that, in order to guarantee the highest possible effectiveness, it is necessary to determine individually the optimal interval between treatment MVCs and the subsequent speed-strength performances - on the basis of suitable measurements. This also applies to the stimulus density, when training with repeated maximum contractions. Generalized instructions would be inappropriate - especially for top-level athletes.

Anaerobic-lactacid loads on the previous day

High anaerobic-lactacid training or competition loads on the previous day impair, or even invert, the effect of MVCs. Furthermore, a smaller increase in performance within the speed-strength series is obviously to be expected. Under these conditions a reduced effectiveness must be expected for training sessions which include maximal speed-strength efforts and combinations of MVCs with speed-strength efforts, as well as training units with maximal contractions exclusively. In the case of aerobic endurance performances like sprinting, jumping, throwing and technique training, no such impairing effect over 24 hours could be observed.

Stretching stimuli

Some fundamental experiments have indicated that even individual stretching stimuli can lead to a considerable reduction of PTP effects (e.g. Hutton et al. 1973). Therefore it is advisable to do no stretching exercises at all between MVCs and speed-strength efforts, and during training with repeated maximal contractions.

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