Effects of Combined Training Loads on Relations Among Force, Velocity, and Power Development

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Catalogue Data

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Mots-clés: entraînement musculaire, relation force–vitesse, puissance musculaire

Abstract/Résumé
The effects of different training programs on the force–velocity relation and the maximum power output from the elbow flexor muscles were examined in 12 male adults. The subjects were divided into two equal groups (G30 + 100 and G30 + 0). In the G30 + 100 group, training was performed with five repetitions at 30% maximum strength (F_{max}) and five isometric contractions (100% F_{max}), and in the G30 + 0 group with five repetitions at 30% F_{max} and five contractions with no load (0% F_{max}). Training was performed 3 days a week for 11 weeks. Maximum power increased significantly in both groups after training. The power increase was significantly greater in the G30 + 100 group. Maximum strength was significantly higher only in the G30 + 100 group, while maximum velocity increased in both groups. No significant difference in strength or velocity gain was observed between the two groups. These results suggest that isometric training at maximum strength (100% F_{max}) is a more effective form of supplementary training to increase power production than no load training at maximum velocity.

Les effets de différents programmes d’entraînement sur la relation force–vitesse et sur le maximum de puissance des fléchisseurs du coude sont étudiés chez 12 hommes divisés en deux groupes équivalents: G30 + 100 et G30 + 0. L’entraînement du premier groupe consiste en cinq répétitions à 30% force maximale (F_{max}) et cinq contractions isométriques (100% F_{max}); l’entraînement de l’autre groupe incorpore les mêmes répétitions mais les cinq contractions se font sans résistance (0% F_{max}). Le programme dure 11 semaines, à raison de

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trois fois par semaine. Les deux groupes améliorent leur maximum de puissance, mais l'amélioration du groupe G30 + 100 est supérieure. Les deux groupes améliorent leur vitesse maximale mais seul le groupe G30 + 100 augmente sa force maximale. Les différences d'amélioration de force et de vitesse des deux groupes ne sont pas statistiquement significatives. Ces observations suggèrent que, pour améliorer la puissance, l'entraînement isométrique à 100% F_max, est une forme d'entraînement additionnel plus efficace qu'un entraînement à vitesse maximale sans résistance.

Introduction

In maximum dynamic contractions, the velocity of muscle shortening decreases with the application of an increased load. According to this phenomenon, known as the force–velocity relation (Hill, 1938), muscle power varies with the load, attaining a maximum value at 30–35% of maximum isometric strength (Hill, 1938; Kaneko, 1974; Wilkie, 1950).

In training based on the force–velocity relation, Kaneko et al. (1983) reported that a training load of 30% of maximum strength most effectively increases maximum power output. They also reported that training with maximum strength is most effective for increasing maximum strength, and training at maximum velocity is most effective for increasing maximum velocity. Moritani et al. (1987) also reported that training with a load of one third of maximum strength significantly increases maximum power. Duchateau and Hainaut (1984) observed that the maximum muscle power of the adductor pollicis demonstrated a larger increase after training with the isometric group as compared to the dynamic group. In recent studies using isokinetic devices, velocity-specific improvements were reported in that training which integrates fast movement improved high velocity strength, whereas slow high-resistance action increased low-velocity strength (Behm and Sale, 1993; Coyle et al., 1981; Kanekisa and Miyashita, 1983; Moffroid and Whipple, 1970).

The effects of training using multiple loads, so-called combined training, has been examined in conjunction programs that combined isometric with isotonic contractions (Belka, 1968; McKethan and Mayhew, 1974), and periodized slow and fast resistance training may produce greater increases in sustained force production than would slow or fast training alone (Doherty and Campagna, 1993). The effects of combining isometric and isotonic training on the swing speed of the arm have also been examined (Smith, 1964; Whitley and Smith, 1966), as well as the effects of various forms of combination training on sprinting (Dintiman, 1964) and jumping ability (Clutch et al., 1983; Toji et al., 1989). Toji et al. (1989) demonstrated that combining either isometric or weight training of knee extensors with repetitions of vertical jumping was more effective than training by vertical jumping alone.

Based on the findings and methods of a study by Kaneko et al. (1983) on the effects of singular training loads on the force-velocity relation of elbow flexors, the current study examines the effects of a combined training program on the relations among force, velocity, and power development.

Methods

SUBJECTS

The subjects were 12 male (ages 21 to 24) undergraduate and graduate college engineering students who had done no special physical training for at least a year.
Table 1  Age and Physical Characteristics of Subjects

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Age (years)</th>
<th>Stature (cm)</th>
<th>Body mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>G30+100</td>
<td>6</td>
<td>22.0</td>
<td>1.0</td>
<td>173.2</td>
</tr>
<tr>
<td>G30+0</td>
<td>6</td>
<td>21.8</td>
<td>1.2</td>
<td>170.4</td>
</tr>
</tbody>
</table>

Figure 1. The modified Wilkie's apparatus used for muscle training and for testing force–velocity relationship. Velocity (V) and isometric (Fmax) were measured at the wrist for the elbow joint at 90°.

Table 1 summarizes their physical characteristics on a group basis. Subjects were fully informed of the procedures and signed a consent form prior to participation.

INSTRUMENTATION

Training and tests of elbow flexion were done using an ergometer having the same basic mechanism as Wilkie (1950) (Figure 1). The subjects performed elbow flexions while sitting in a chair with the ergometer positioned at the side of the body. The dominant upper arm was placed on a platform, with the forearm in an upright position while the wrist was linked to the instrumentation. For dynamic contractions, the elbow was impulsively flexed with maximum effort from 140° to 70°. During this flexion, a long metal arm rotated parallel with the forearm, and a load
suspended from a shorter metal arm was raised. Maximum isometric strength was measured with the long arm secured at 90°.

FORCE– VELOCITY RELATION AND POWER DETERMINATION

The force–velocity relation and power were determined, before and after training, with loads of 0, 10, 20, 30, 45, 60, and 100% of maximum strength (F<sub>max</sub>) at 90° of the elbow joint. Four trials were performed at each load: the first two trials at each load from the lightest to the heaviest, followed by two trials each in reverse order (Hill, 1938). The maximum velocity was determined at the load of 0% F<sub>max</sub> (no load). The F<sub>max</sub> and the maximum velocity was the calculated mean of the four trials. The velocity-time curves were recorded with a linear velocity transducer (Sheivitz 7L6VT-Z) connected to a long metal arm and converted into the wrist velocity (V). An electrogoniometer was also attached to the axis of the long metal arm so that a determination of the instant the elbow passed 90°, at which force and velocity were measured, could be made. The force and velocity values so obtained were fitted to Hill’s characteristic equation (Hill, 1938) to determine the force–velocity relation:

\[(F + a)(V + b) = (F_{max} + a)b,\]  \hspace{1cm} (1)

where F is force, V is the velocity, F<sub>max</sub> is the maximum isometric strength, and a and b are constants. Power (FV) was calculated from the following equation, which is derived from Equation 1:

\[FV = b \cdot F \left( \frac{F_{max} + a}{F + a} - 1 \right).\]  \hspace{1cm} (2)

Maximum power (FV<sub>max</sub>) was obtained on the basis of the load (F<sub>in</sub>) calculated from the following equation, which is derived from differentiating Equation 2:

\[F_{in} = a \left( \frac{F_{max}}{\sqrt{1 + \frac{F_{max}}{a}} - 1} \right).\]  \hspace{1cm} (3)

The maximum power (FV<sub>max</sub>) is expressed as

\[FV_{max} = \left( \frac{F_{in}}{F_{max}} \right)^2 F_{max} \cdot V_0,\]  \hspace{1cm} (4)

or equivalently,

\[F_{max} = \left[ \frac{a}{F_{max}} \left( \frac{F_{max}}{\sqrt{1 + \frac{F_{max}}{a}} - 1} \right) \right]^2 F_{max} \cdot V_0.\]  \hspace{1cm} (5)

TRAINING METHODS

The subjects were divided into two groups of 6 subjects each (Table 1). With the use of the ergometer mentioned above, training was performed 3 days a week nonconsecutively for 11 weeks, with the programs as follows:
• Group G30 + 100: combined training in which subjects exerted maximum power output five times at 30% $F_{\text{max}}$ and five times at 100% $F_{\text{max}}$, for 3 s each, with a 10-s interval.
• Group G30 + 0: combined training in which subjects exerted maximum power five times at 30% $F_{\text{max}}$ and five times at 0% $F_{\text{max}}$ (no external load).

STATISTICAL DESIGN

Ordinary statistical methods were used to calculate means and standard deviations. A paired $t$ test was used to test the significance of individual differences between pre- and posttraining results. The mean values in the G30 + 100 and G30 + 0 groups were compared with an unpaired $t$ test for two means, with the level of significance set at .05.

Results

Figure 2 shows means and standard deviations of the velocities (m/s) $V_0$, $V_{10}$, $V_{20}$, $V_{30}$, $V_{45}$, and $V_{60}$ obtained at loads of 0, 10, 20, 30, 45, and 60% $F_{\text{max}}$, respectively, before and after training for both groups. The figure also contains force–velocity curves from Equation 1 and force–power curves from Equation 2. Constants related to the characteristics of these curves are shown in Table 2, along with corresponding values of maximum strength and maximum power. No significant differences were observed among the groups before training in $FV_{\text{max}}$, $F_{\text{max}}$, or $V_{0}$, so the initial conditions of these variables were considered equivalent for both groups.

![Graphs](image)

**Figure 2.** Force–velocity and force-power relations at pre- and posttraining periods in two different training groups. Arrow indicates load at which maximum power appeared. *Significant difference between pre- and posttraining ($p < .05$). **Significant difference between pre- and posttraining ($p < .01$).
Table 2  Changes in Isometric Strength ($F_{\text{max}}$ (N)), Dynamic Consants ($a$, $b$ and $a/F_{\text{max}}$) and Maximum Power ($FV_{\text{max}}$ (W)) at the pre- and post-training periods.

<table>
<thead>
<tr>
<th>Group</th>
<th>$F_{\text{max}}$ (N)</th>
<th>$a$</th>
<th>$b$</th>
<th>$a/F_{\text{max}}$</th>
<th>$FV_{\text{max}}$ (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td></td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>G30+</td>
<td>249.9</td>
<td>294.7*</td>
<td>82.8</td>
<td>91.2</td>
<td>1.6</td>
</tr>
<tr>
<td>100</td>
<td>(26.2)</td>
<td>(29.9)</td>
<td>(6.8)</td>
<td>(17.8)</td>
<td>(0.1)</td>
</tr>
<tr>
<td>G30+</td>
<td>258.1</td>
<td>272.6</td>
<td>94.2</td>
<td>91.7</td>
<td>1.8</td>
</tr>
<tr>
<td>0</td>
<td>(30.0)</td>
<td>(17.7)</td>
<td>(14.8)</td>
<td>(12.3)</td>
<td>(0.5)</td>
</tr>
</tbody>
</table>

Note. Standard deviations are in parentheses.

* $p < .05$, ** $p < .01$.

Increases in velocity were seen at relatively light loads ($V_{op}, V_{op}, V_{20},$ and $V_{30}$) in the G30 + 0 group, while significant increases were observed in all velocities from $V_{op}$ to $V_{0}$ in the G30 + 100 group (Figure 2). Maximum strength ($F_{\text{max}}$) increased significantly only in the G30 + 100 group, as did maximum power ($FV_{\text{max}}$) in both groups, whereas no significant changes were observed in any constants ($a$, $b$, or $a/F_{\text{max}}$) (Table 2).

As shown in Figure 3, the maximum power increased significantly after training in both groups. The increase of maximum power ($+\Delta FV_{\text{max}}$) was significantly greater in the G30 + 100 group than in the G30 + 0 group. The maximum strength in both groups increased significantly after training, but no significant difference was observed between the increases in strength gain ($+\Delta F_{\text{max}}$). The magnitude of increases in maximum velocity ($+\Delta V_{0}$) was about the same, with no significant differences between the two groups.

Discussion

The training programs dealing with “specificity of training” have mostly been done with one specific training load for each group (Caiozzo et al., 1981; Coyle et al., 1981; Kanehisa and Miyashita, 1983; Kaneko et al., 1983; Sale and MacDougall, 1981). This “singular training” method differs from the “combined training” usually practiced. Smith (1964) reported an increase in both strength and speed from a combination of isotonic and isometric training (isotonic-isometric training), while Whitley and Smith (1966) reported that, from an increased swing speed of the arm, isometric-isometric training was equally effective as isotonic training alone. In a study by Belka (1968), who used static-dynamic training as well, only dynamic strength increased significantly. The combined training of G30 + 100 in the present study (corresponding to the isometric-dynamic training) clearly showed a greater increase in maximum strength than the another group, and maximum speed and maximum power increased as much as in the other group.
In a combined program of isometrics-isotonics training using a weight machine, McKethan and Mayhew (1974) observed an increase in strength but not vertical jump performance. In a study on the effects of combined training on the vertical jump, Toji et al. (1989) reported that a combination of vertical jumping and strength training was more effective than vertical jump training alone.

The results of the present study support the findings of Toji et al. (1989), although the exercise conditions differ. In the vertical jump, the load was the individual body weight. Lunar jump studies (Cavagna et al., 1972) have revealed that the maximum power for a vertical-jump type of exercise appears under the load condition of body weight (1G). Since maximum power appears at 30% $F_{\text{max}}$, body weight imposes a load equivalent to 30% $F_{\text{max}}$ for an isometric squat action. Thus, both studies share the common factor of training loads eliciting maximal power and can therefore be considered comparable in that respect. The effect of training in the $G30 + 0$ group is in agreement with our previous findings on vertical jump training (Toji et al., 1989), suggesting that improvements in the dynamic characteristics of muscles may be closely related to the increase in power output in a vertical jump.

The mechanical characteristics of muscle itself can be systematically studied by considering the force–velocity relation (Hill, 1938; Kaneko, 1974). The ratio of $df_{\text{max}}$, describing the concavity of the force–velocity curve can be influenced by differences in muscle fiber composition (Close, 1972; De Koning et al., 1984) or by the effects of training (Duchateau and Hainaut, 1984; Kaneko et al., 1983). In the present study, characteristic changes (parallel shift) in the force–velocity curve due to training took place more or less in both groups (Figure 2). No
significant changes were observed in the $aF_{\text{max}}$ ratio in the present study, and the $F_{\text{d}}/F_{\text{max}}$ ratio in Equation 4 tended to decrease, suggesting that the increase of $FV_{\text{max}}$ might have originated from an increase in $F_{\text{max}}$ or $V_{0}$.

Regarding physiological factors that might enhance maximum power, Moritani et al. (1987) reported a significant increase in maximum power by the training with a load of 1/3 $P_{0}$, and pointed out both increases in electromyograph (EMG) amplitude and synchronization of muscle action potentials. In a training program designed to increase torque and speed, Behm and Sale (1993) have shown that the intent to move rapidly is more important than actual movement velocity as a training stimulus. In the study by Duchateau and Hainaut (1984), the maximum power of the adductor pollicis demonstrated a larger increase after isometric training than after dynamic training, whereas the twitch rate of force development demonstrated a larger increase after dynamic training than after isometric training.

By taking these findings into consideration, the greater increase in maximum power in group G30 + 100 of the current study can be attributed to such factors as improvement in strength and related muscle hypertrophy (Fukunaga and Sugiyama, 1978), and improvement in neuromuscular coordination (Moritani, 1993).

In conclusion, a combined program of training, isometric strength and maximum power would be a more effective form for increasing power production than a program of combining maximum velocity and maximum power training.

References


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