Coordination, the determinant of velocity specificity?

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Almåsbakk, Bjorn, and Jan Hoff. Coordination, the determinant of velocity specificity? J. Appl. Physiol. 80(5): 2046–2052, 1996.—Initial strength gains were examined in the context of learning a new skill. Forty female volunteers were randomly assigned to one of four groups: a bench-press training group utilizing heavy loads in its training, a bench-press training group utilizing almost no load, an alternative training group using different exercises, or a control group that did not train. Training period was 6 wk, with three training sessions per week. Emphasis was put on keeping the coordination and muscular adaptation demands in the bench-press groups as invariant as possible. Bench-press training with a light or with a heavy weight was shown to be equally effective in improving the maximal velocity of contraction for a given absolute resistance. Mean velocity with loads of 0.37, 6.6, 16.6, and 20 kg improved by 21.1, 15.8, 16.9, and 19.5%, respectively. No significant differences in the percent improvement at the four different loads were apparent, indicating that no significant velocity-specific adaptations were present. The bench-press training group, utilizing heavy loads in its training, was the only group with improved one repetition maximum. Overall, findings point to the development of velocity-specific strength gains.

STUDIES OF RESISTANCE TRAINING have shown specific adaptations of muscular force depending on the training program applied (26). Velocity-specific adaptations to resistance training are a major subject of interest to the researcher, the coach, and the athlete alike. One consensus of opinion is that velocity specificity (despite a lack of agreement over what constitutes high and low velocity) is the way to produce optimal strength and power improvement at a given test or performance speed and that the further the velocity of a movement deviates from the trained velocity, the less effective the training will be (5, 8, 14, 15, 19).

That this hypothesis is not universal and that even within that consensus opinions differ as to the mechanisms underlying velocity-specific adaptations is attested to by the literature. A number of studies, for example, have shown that an increase in maximal dynamic muscle strength [one repetition maximum (1RM)] in a well-defined movement is followed by an increase in the velocity of the same movement (4, 6, 7, 27, 31). Although these studies point to the possibility of increasing movement speeds by using heavy-resistance training, they do not discuss this possibility from a movement or velocity specificity of training point of view. Voigt and Klausen (30) showed that even though heavy-resistance training by itself does not improve the speed of a skilled unloaded movement, it does enhance the gain in movement speed if it is combined with specific training.

Training with heavy loads, which, in turn, implies low velocity, primarily affects the high-force part of the force-velocity curve, whereas training with light weights and high velocities primarily affects the high-velocity portion of the curve (15, 16). Petersen et al. (22) found, in contrast, that resistance training at high velocity seems to be no more effective in increasing high-velocity gains in performance than does training at low velocity. Similarly, Doherty and Campagna (9) found that previously untrained subjects exhibited similar increases in maximal force production at both high and low velocities regardless of the velocity at which the training was carried out. Two studies (5, 14) showed that training at high velocity improves performance only at high velocities, whereas training at low velocity results in an improvement at all test velocities. This is not, however, consistent with the results of Moffroid and Whipple (19) and Coyle et al. (8), who showed an improvement at all test velocities after training at high velocities, whereas training at low velocities only improved performance at the same or a slightly higher test velocity. Behm and Sale (2) demonstrated the importance of the instruction given to subjects. It was the intended rather than the actual movement speed that created a high-velocity adaptation. Their findings point to this as a possible explanation for the divergent findings of the previously mentioned studies. The two studies showing general velocity improvements (9, 22) specifically state that their subjects were instructed to carry out the contractions as fast as possible.

Although the majority of studies support some kind of velocity-specific adaptation, there is enough controversy to warrant approaching the question from another angle. A resistance-training program will increase the generation of force within a muscle or muscle group (1). A mechanism responsible for a velocity-specific effect is unknown. However, one can limit the number of possibilities to two broad velocity-specific adaptations: 1) within the muscle, altering its force-velocity characteristics, or 2) within the nervous system, altering the recruitment pattern (23).

In strength training, the increase in voluntary neural drive accounts for the largest proportion of the initial strength increment, and, thereafter, both neural adaptation and hypertrophy take place with further increases in strength, with hypertrophy becoming the dominant factor (12, 20, 21). A velocity-specific adaptation within the muscle seems an unlikely explanation for the results of the previously discussed studies.

In a movement requiring a large amount of force, the timing of the muscle contraction is important. The ability of the nervous system to activate agonists,
synergists, and antagonists in synergy is fundamental to the force produced. During the first week of a training program, an improvement in the ability to activate and coordinate contraction of the muscles involved in the movement trained has been shown to be the important factor (24). A possible explanation for velocity-specific adaptations might, therefore, be that training programs reflect the acquisition of skill and that training improves such activation at the trained velocity (13, 23). Siegel and Davis (28) demonstrated that when learning a novel skill, the greatest improvement is at the velocity used in training. Further support for this concept is the finding that control groups also show small improvements at all tested speeds (19, 28), effects of mental practice on strength (32), and strength-training effects on the contralateral limb (11, 20, 21).

No conclusive evidence has been reported from any study of velocity- or load-specific adaptations, which would exclude adaptations within the muscle. It is probable that an increase in voluntary neural drive is the mechanism behind this initial strength improvement. On this basis, the postulate of Rutherford (23) and Jones et al. (13) that training improves the subject's ability to activate muscle groups at the trained velocity would appear to be a reasonable explanation for velocity- and load-specific adaptations. Thus the results of studies on velocity-specific adaptations have to be seen in the context of the learning of a new skill. If, therefore, performance demands in terms of coordination and activation of muscles are kept as invariant as possible, it should be possible to produce equivalent effects on the force-velocity curve with the same training program but with loads from different zones of the curve. This postulate is explored in the experiment to be reported.

METHODS

Subjects. The subjects were 40 female students recruited voluntarily from different university departments. They had no previous background in strength training. The subjects were randomly divided into four groups. Personal data on age, height, weight and bench-press lifting height1 are given in Table 1.

Design. A between-subjects design with 4 groups and 10 subjects in each group was used: bench press utilizing heavy loads for maximal strength training (1 RM; BPH group), bench press using very light weights (a wooden stick; constituting a negligible external load; BPL group), same muscles trained (pectoralis and triceps bracci) using, alternately, shoulder lateral flexion and elbow extension (Alt group) and control group that did not train but carried out the pre- and posttests (Con group).

Four subjects withdrew from the study, two because of travel abroad, one for personal reasons, and one due to an injury (not related to the training carried out in this study).

Table 1. Physical characteristics

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Age, yr</th>
<th>Height, cm</th>
<th>Weight, kg</th>
<th>Lifting height, cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Con</td>
<td>9</td>
<td>21.6±3.0</td>
<td>166±4</td>
<td>64.5±15.0</td>
<td>45±3</td>
</tr>
<tr>
<td>Alt</td>
<td>8</td>
<td>22.0±3.0</td>
<td>170±8</td>
<td>66.8±3.2</td>
<td>46±4</td>
</tr>
<tr>
<td>BPH</td>
<td>10</td>
<td>20.8±1.0</td>
<td>168±4</td>
<td>64.9±10.5</td>
<td>46±3</td>
</tr>
<tr>
<td>BPL</td>
<td>9</td>
<td>22.2±2.5</td>
<td>166±5</td>
<td>63.2±5.0</td>
<td>44±3</td>
</tr>
</tbody>
</table>

Values are means ± SD; n, no. of subjects. Con, control group; Alt, alternative training of involved muscles; BPH, bench press with heavy load; BPL, bench press with light load.

Training. The BPH, BPL, and Alt groups (unless otherwise stated) were involved in three training sessions per week for 6 wk, with three sets of seven repetitions per session. All groups were instructed to maximize their mobilization in initiating the concentric part of a press or lift, i.e., the concentric part of each lift was to be carried out with the intent of making a high-speed contraction. The BPH and Alt groups were instructed to increase the loads utilized if they managed more than seven repetitions in their final set; i.e., they were to keep the loads utilized in training at 80–85% of their maximal performance. The BPH and BPL groups were instructed in where to position their hands on the bar (just outside their shoulder) so that a consistency of positioning was maintained under both conditions. They were also given the same lifting-technique instructions. More specifically, the BPL group was taught the technique necessary to do heavy lifts. The instructions included statements about starting position, breathing pattern, rhythm of the lift performance, movement plane for the bar, and rest intervals between lifts and sets. The subjects were given instructions the first three sessions and thereafter once a week for the remaining 5 wk.

The BPH group during the first training week trained at 10 rather than 7 repetitions per set to learn the correct technique with a lower load and to minimize the risk of injuries. The subjects began their repetitions with a bar load of 80% of the 1 RM obtained in the pretest. They were instructed to increase the load by 2.5 kg each time they managed to raise their repetition rate above seven during the last set of the training session. The BPL group lifted only a wooden stick weighing 0.37 kg. For the Alt group, the external load was adjusted to match its training state. The subjects were instructed to increase their load by 1.5 kg every time they managed to carry out more than seven repetitions during the last set of the training session.

Measurements. For both tests and training, weight-lifting equipment type T-100G Eleiko was used. Weight tolerance was stated to 0.01%. A bench-press bench was mounted on a force platform. The barbell and the subject's shoulders as- sumed a position along a line through the center of the platform. The force platform was 60 × 100 cm, and vertical force was collected by means of four cells, one at each corner of the platform. The force cells were type CL 100 (Scan Sense). Measuring range for the cells is stated to be 0–500 kg. Linearity was stated to 0.1%, and the reproducibility was stated to 0.1% along the total range of the cells. Calibrating routines as well as data collection and analyses were carried out with software developed for the platform (O. Arntzen, Norwegian University of Science and Technology, Dragoy). Sampling frequency was 2 ms (0.002 s). A computer (Compaq 486, 33 MHz) was used for sampling and analyses. The setup of the system made it possible to examine the force-time curves immediately after each lift. The size of the platform made it impossible to place the whole bench on top of the force platform. Two of the legs of the bench were placed outside the platform, which gave a reduction in peak force registered on

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1 Bench-press lifting height is the distance measured from the lowest position of the bar on the chest to the highest position when the arms are fully stretched (i.e., the vertical distance through which the bar travels during a press).
the platform of ~10–15% depending on the weight of the subjects. Only time variables and individual changes were, however, used.

The test series consisted of the following bench-press sequence: isometric lift, dynamic lifts of 0.37, 6.6, 16.6, and 20 kg, and thereafter an increase by 5 kg until the subject failed to manage the lift. A reduction was then made by 2.5 kg to obtain an accuracy of 2.5 kg in the 1-RM test. A 2-min rest was given between each press, and a 3-min rest after failing. One series of tests lasted ~15 min. Each subject was individually tested at the same hour of the day. Warm-up was standardized by 15 min of work on a treadmill or cycle ergometer and 5 bench presses at 50% of the subject's 1 RM. Control of lifting technique was made during the warm-up to ensure that subjects lowered the bar slowly and carried out a maximal mobilization in the concentric part of the movement. Each bench press was carried out only once and repeated only when the subjects failed to conform to the required manner of execution. The force-time curve was obtained for each lift. The platform was calibrated for each lift to register zero force after the subject had lifted the barbell off the rack. Verbal instructions about lifting procedure were given before each lift.

The independent variable for the study was the force-time curve (Fig. 1). Velocity-specific adaptations were measured by calculating the average speed through the bench press with loads of 0.37, 6.6, 16.6, and 20 kg, which were the loads all subjects succeeded in lifting in the pretest. Maximal strength was induced by the 1 RM.

The subjects were familiarized with the test procedures before the first data acquisition. A pretest was followed at the end of third training week by a second test, which, in turn, was followed by a third test immediately after the sixth training week. The second test was intended as a motivational factor for the subjects and the results were not included in the analysis.

The force-time curve gives time taken to carry out the press (as shown in Fig. 2). Mean velocity \( v \) for the press was calculated as \( v = \text{lifting height/time taken to carry out the press} \). The dependent velocity variables used were mean velocities for the concentric part of the bench press with 0.37-, 6.6-, 16.6-, and 20-kg loads.

Statistical analysis. Statistical analysis was carried out with SPSS 6.0 for Windows. The data were analyzed with analysis of variance (ANOVA). Changes in velocity were analyzed with a three-factor ANOVA with repeated measures on the last factor (groups × velocities × test times). The isometric data and 1 RM were analyzed by a two-factor ANOVA with repeated measures on the last factor (groups × test times). Statistical significance was used \( P < 0.05 \). Descriptive statistics include means ± SD for tables and means ± SE for figures.

RESULTS

Velocity of bench press. The mean ± SD scores for the dependent variable velocities of bench press are presented in Table 2. No significant group × time interaction was found between the BPH and BPL groups \([F(4, 14) = 0.60; P = 0.671]\). For subsequent analysis, therefore, the scores on these variables were pooled [combined bench press (BPC)].

Figures 3–5 show the velocity adaptations collapsed across bench-press training groups (BPC), the Alt group, and the Con group, respectively. Significant group × time interactions were found for BPC, \([F(4,23) = 5.81; P = 0.002]\). For the Alt group, the interaction was not significant \([F(4,12) = 1.33; P = 0.316]\); i.e., initial strength-training effects are probably task specific. The lack of group × time interaction between the BPH and BPL groups, combined with the significant increase in the collapsed pre-post measurements in the BPC group, suggests that training with a light or with a heavy weight is equally effective in bringing about training effects for the bench-press movement with different loads in the early stages of a training program.

Mean percent measures of improvement from pre- to posttest, all of which were significant, for the BPC group were 21.1, 15.8, 16.9, and 19.5% with loads of 0.37, 6.6, 16.6, and 20 kg, respectively. Within the BPC group, there were no significant differences in the percent improvement obtained at the four different loads \([F(3,54) = 0.66; P = 0.578]\). These results indicate that no significant velocity-specific adaptations were present either from the two different loads utilized in training or the training regimen per se.

Rate of force development. Rate of force development was measured as the time the subject needed to develop 25 and 50% of isometric peak force \( t_{ipf25\%} \) and \( t_{ipf50\%} \), respectively. No significant differences in performance were found between the BPH and BPL groups for the
Values are means ± SD; n, no. of subjects. $v_0$, $v_4$, $v_{16}$, and $v_{20}$, mean velocity (in m/s) for concentric part of bench press at 0.37-, 6.6-, 16.6-, and 20-kg load, respectively; 1 RM, 1 repetition maximum (in kg); Pre and Post, before and after testing; BPC, combined BPH and BPL groups.

$F_{t_{0.25}}$ [F(1, 17) = 0.13; P = 0.719] or for the $t_{p_{0.50}}$ [F(1, 17) = 1.31; P = 0.268]. For subsequent analysis, therefore, the scores on these variables were pooled. Again, this result would indicate that the coordination and activation demands in training overshadow the velocity at which the training was carried out.

Figures 6 and 7 show the mean percent improvement for all groups from pre- to posttest. Although the BPC group shows a large increase in rate of force development, with posttest values exceeding pretest values by 29.7% [t_{0.25} F(1,26) = 2.49; P = 0.064] and 33.2% [t_{p_{0.50}} F(1, 26) = 2.27; P = 0.072], respectively; the results did not reach an acceptable level of significance. Although there were no significant differences between the BPH and BPL groups, the lack of improvement when compared with the Con group indicates no significant effect due to training on the rate of force development variables.

Maximal dynamic strength. Maximal dynamic strength was measured as the 1 RM in the bench press.

Figure 8 shows the improvement in weight. A significant difference in improvement between the bench-press groups was observed [F(1,17) = 5.74; P = 0.028]. Subsequent analysis revealed, for the BPH group, a significant 1 RM × time interaction [F(1, 17) = 9.14; P = 0.008], whereas no significant interactions were found for the BPL or Alt group. This suggests that even in the early phase of a strength-training program, the learning of the movement by itself is not sufficient to improve maximal strength. The use of weights, in this case 80–85% of the subjects’ maximum, is necessary to improve maximal dynamic strength.

DISCUSSION

The two bench-press groups, BPH group training with progressive loads at 80–85% of 1 RM and BPL group training with a wooden stick weighing 0.37 kg, showed equivalent effects (no significant group × time interaction; P = 0.671) on the force-velocity curve. This finding points to coordination as being the determining factor in early velocity-specific strength gains. This finding is in line with Rutherford and Jones (23) and Jones et al. (13) that training programs reflect the acquisition of skill and that training improves such activation at the trained velocity. The improvements in movement speed are also consistent with previous reports (4, 6, 7, 27, 31). If the velocity of training were to be defined in terms of the actual velocity of the training movement, then the BPL group would be classified as a high-velocity training group, whereas the BPH group would be classified as a low-velocity training group. Mean velocity with loads of 0.37, 6.6, 16.6, and 20 kg improved by 21.1, 15.8, 16.9, and 19.5%, respectively. No velocity-specific training response was found. This is counter to some of the previously reported results (e.g., Refs. 2, 15, 19) but is supportive of others (9, 22).
The absence of a velocity-specific training effect can possibly be explained in the terms of the invariance in coordination and muscular activation demanded by the two bench-press training groups despite the variance in the loads to be lifted. In typical training regimens with heavy loads or with an isokinetic apparatus, little or no emphasis is put on a rapid rate of force development or explosive movements. One performance demand with which the subjects had to cope was that of carrying out the concentric part of the movement as fast as possible. This was a constraint previously imposed by Behm and Sale (2), who, in contrast to the present finding, found a high-velocity-specific training effect. A possible explanation of the divergent findings is to be found in the instructions given to the subjects. Whereas, in the present experiment, emphasis was placed on the learning of the whole movement (the bench press), in their study, Behm and Sale placed emphasis mainly on the initiation phase of the movement. By using a dynamic exercise such as the bench press, subjects were able to accelerate the bar for most of the movement duration, whereas in isokinetic exercises, the movement velocity is kept constant. In this way, subjects were able to explore and exploit the coordination dynamics implicit in the subject-environment interaction, thereby discovering a more optimal solution to the problem. This exploration could lead to the development of more efficient coordination and activation patterns within the nervous system, which could be a more dominating factor than any adaptations due to the speeds at which the movement was carried out. Furthermore, the present study was a between-subjects design that included a control group, whereas Behm and Sale trained the legs of their subjects under two different training regimens, thereby precluding the control of a previously reported transfer of training across limbs (21).

Support for the interpretation of the findings presented here is provided in two studies that also failed to find a velocity-specific training effect, namely those of Petersen et al. (22) and Doherty and Campagna (9). Both of these studies put emphasis on the fact that the subjects were required to carry out the exercise demands of the training with the highest possible intensity. Moreover, the study of Petersen et al. (22) used isokinetic training, which would seem to indicate that the muscle action explanation for a non-velocity-specific finding is not a valid one.

In contrast to the bench-press training groups, the Alt group did not show any significant improvement on
the force-velocity curve (see Fig. 4). Given the interpretation of the results of the bench-press groups being presented here, this is not too surprising because the subjects in this group trained with a very different movement pattern (25, 26). An increase in voluntary neural drive accounts for the best part of initial strength gains (12, 20, 21). An increase in the voluntary neural drive in the Alt group does not lead to improvement in the bench-press tests. This could strengthen the importance of neural adaptations, and specifically the learning of coordination patterns, in strength training. Improvement in the bench-press tests in the Alt group would probably have been due to morphological adaptations within the muscle that, in principle, could be transferred to different movement patterns.

Although the percent improvement in rate of force development variables for the BPC group was rather large, it was not significant. Previous work had reported increases in the rate of force development after strength training (2, 12). The rate of force development data were gathered by an isometric test, whereas the training involved concentric and eccentric movements. Thorstensson et al. (29) found that this way of training led to relatively small improvements in isometric force. A lack of increase in rate of force development isometrically after dynamic training has been found in a number of studies and has been attributed to training-mode specificity (e.g., Ref. 10). A variable training effect on the rate of force development within the training groups was also found in the present study, which is a returning problem in many strength-training studies. The results indicate that repeating the test by itself gives better performance, with an improvement in the Con group of 10 and 18% (Figs. 6 and 7). However, no definitive explanation for the lack of significant improvement in the rate of force development can be stated.

The difference in improvement between the BPH (8.0 kg) and BPL (4.8 kg) groups in maximal dynamic strength shows that even in the early stages of a strength-training program, the use of heavy resistance (in this case 80–85% of 1 RM) is necessary to develop maximal strength. The BPH group showed the expected development of maximal dynamic strength (3). A number of studies have studied the effect on maximal strength when different loads were utilized with the same training program and have shown differing improvements [see Ref. 1 for a review]. The results of the present study indicate that with regard to improvements in 1 RM, the use of heavy resistance is a more dominant factor than coordination improvements alone, even in the early stages of training.

In the introduction to this study, it was stressed that the results of studies on velocity adaptation had to be seen in the context of the learning of a new skill, i.e., velocity-specific adaptations have to do with the learning of a velocity-specific skill. Siegel and Davies (28) demonstrated that, when learning a new skill, the greatest training improvement is brought about at the velocity used in training. The novelty introduced in the present experiment to explore this proposition further was the use of two groups utilizing the same coordination patterns but training with markedly different loads ranging from negligible to high. The results confirmed that there was no difference between the two groups at submaximal performance (the velocity variables), but there was a significant difference at maximal performance. This provides positive support for the contention here that initial strength gains are brought about by the developing coordinative structure, whereas the heavier training weight utilized by the BPH group gave it the necessary advantage at maximal performance. This would be in line with the reported improvements in control groups in the present study and in the studies by Moffroid and Whipple (19) and Siegel and Davies (28).

The findings presented here have significant implications for both the coach and athlete. Maximal advantage would be gained if movements were to be trained with a high resistance and rapid action. This would, given time, have the included advantage (or in some sports perhaps disadvantage) of muscular growth (17, 18). Hypertrophy would also enhance performance at a range of velocities.

The results clearly show the importance of the instruction given to the subjects and clearly underline the proposal that nervous adaptations are critically dependent on the way the muscles are activated by the nervous system. The proposition put forward here that improvement in activation and coordination is the dominant factor in velocity-specific strength gains needs to be explored in other contexts.

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