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MUSCULAR ADAPTATIONS TO COMBINATIONS OF HIGH- AND LOW-INTENSITY RESISTANCE EXERCISES

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ABSTRACT. Goto K., M. Nagasawa, O. Yanagisawa, T. Kizuka, N. Ishii, and K. Takamatsu. Muscular adaptations to combinations of high- and low-intensity resistance exercises. *J. Strength Cond. Res. 18(4):000–000. 2004.*—Acute and long-term effects of resistance-training regimens with varied combinations of high- and low-intensity exercises were studied. Acute changes in the serum growth hormone (GH) concentration were initially measured after 3 types of regimens for knee extension exercise: a medium intensity (approximately 10 repetition maximum [RM]) short interset rest period (30 s) with progressively decreasing load ("hypertrophy type"); 5 sets of a high-intensity (90% of 1RM) and low-repetition exercise ("strength type"); and a single set of low-intensity and high-repetition exercise added immediately after the strength-type regimen ("combi-type"). Postexercise increases in serum GH concentration showed a significant regimen dependence: hypertrophy-type > combi-type > strength-type ($p < 0.05$, $n = 8$). Next, the long-term effects of periodized training protocols with the above regimens on muscular function were investigated. Male subjects ($n = 16$) were assigned to either hypertrophy/combi (HC) or hypertrophy/strength (HS) groups and performed leg press and extension exercises twice a week for 10 weeks. During the first 6 weeks, both groups used the hypertrophy-type regimen to gain muscular size. During the subsequent 4 weeks, HC and HS groups performed combi-type and strength-type regimens, respectively. Muscular strength, endurance, and cross sectional area (CSA) were examined after 2, 6, and 10 weeks. After the initial 6 weeks, no significant difference was seen in the percentage changes of all variables between the groups. After the subsequent 4 weeks, however, 1RM of leg press, maximal isokinetic strength, and muscular endurance of leg extension showed significantly ($p < 0.05$) larger increases in the HC group than in the HS group. In addition, increases in CSA after this period also tended to be larger in the HC group than in the HS group ($p = 0.08$). The results suggest that a combination of high- and low-intensity regimens is effective for optimizing the strength adaptation of muscle in a periodized training program.

KEY WORDS. resistance training, growth hormone, muscular strength, muscular endurance, muscle hypertrophy, periodization

INTRODUCTION

Regimens in resistance training have been generally categorized into two major types with different objectives: "strength-type" and "hypertrophy-type" (4). The former consists of high-intensity exercises (above 90 % of 1 repetition maximum [RM]) with low repetitions and long rest periods between sets. This type of regimen is used for gaining strength. On the other hand, the "hypertrophy-type" regimen consists of moderate-intensity exercises (60 to 75% of 1RM) with higher repetitions and shorter rest periods between sets. This type of regimen has been thought to be effective in gaining muscle size (18).

Recently, the use of a single particular type of regimen throughout the training period has become less common; instead, multiple training regimens are used in a periodized fashion, because it is thought that they cause greater strength gains in muscles. In fact, several studies have shown higher performance gains by periodized programs than by nonperidodized programs (6, 20). A periodized training protocol in which a phase aiming for muscle hypertrophy is followed by a phase aiming for neural adaptation (strength phase) is especially thought to optimize the adaptation of muscle (6).

The mechanism underlying the difference between the effect of a strength-type regimen and that of a hypertrophy-type regimen involves many factors (i.e., mechanical, metabolic, and neural). Among these factors, actions of anabolic hormones such as growth hormone (GH) and testosterone may be important, because these hormones have been shown to facilitate protein synthesis in the muscle cells, thereby enhancing muscle hypertrophy (8). Although any type of resistance exercise appears to stimulate secretions of anabolic hormones, no great hormonal response, especially that of GH, has been shown to occur after high-intensity and low-repetition exercises such as those used in the strength-type regimen (12, 16, 17).

We recently investigated the GH responses to varied exercise regimens in which a single set of exercise at 90–50% of 1RM was added after a strength-type regimen. The results showed that performing an additional set of exhaustive exercise at 50% of 1RM added immediately after a strength-type regimen (combi-type) caused marked increases in lactate and GH concentrations in blood (10). Based on some earlier studies on the relationships between the magnitude of anabolic hormone responses, strength improvement (13), and muscle fiber hypertrophy (22), we postulated that the combi-type regimen may be highly effective for gaining muscular size and strength simultaneously. However, the effect of such an exercise regimen has not been well documented. Greater training effects could also be expected when the combi-type regimen is used during the strength phase subsequent to the hypertrophy phase in a periodized training program.

The present study aimed to examine the effects of a combi-type regimen on muscle function and morphology in a periodized training program. Interest was focused on muscle adaptations to the combi-type regimen subsequent to the hypertrophy phase; these adaptations were

TABLE 1. Workout style in each group.*

Phase	Hypertrophy phase (0–6 wk)	Strength phase (7–10 wk)
Regimen	Hypertrophy type (HC/HS groups)	Combi type (HC group) Strength type (HS group)
Exercise	Leg press/leg extension	Leg press/leg extension
Frequency	2 d/wk	2 d/wk

* HC = hypertrophy/combi; HS = hypertrophy/strength.

compared with those in the strength-type regimen subsequent to the hypertrophy phase. Additionally, a pilot study on hormone secretion in each training regimen was conducted.

METHODS

Experimental Approach to the Problem

Seventeen active male subjects aged 19–22 years participated in the study. They were undergraduate students in the faculty of medicine at the University of Tsukuba, and each had some regular sport activity (a few times per week) and experience with recreational resistance training within the past 4 years. Although physically active, all subjects were considered untrained, and they had not participated in a regular resistance training program for at least 6 months prior to the present study. They were informed about the experimental procedure to be used as well as the purpose of the study, and their written informed consent was obtained. The study was approved by the Ethics Committee for Human Experiments, Institute of Health and Sport Sciences, University of Tsukuba.

Study participants performed leg press and leg extension twice a week for a period of 10 weeks. Because the major objective of the present resistance training program was to gain muscular strength and size (7), a linear periodized protocol including a muscle hypertrophy phase (initial 6 weeks) and a strength phase (subsequent 4 weeks) was used. Seventeen subjects were assigned to either the hypertrophy/combi (HC) group ($n = 8$) or the hypertrophy/strength (HS) group ($n = 9$). During the hypertrophy phase (weeks 0–6), both groups performed the same H-type regimen as described in the previous experiments for acute hormonal responses. After the hypertrophy phase, they were divided into HC and HS groups so as to match the strength improvements in each group. During the subsequent strength phase (weeks 7–10), the HC and HS groups performed combi-type and S-type regimens, respectively (Table 1 and Figure 1). Both groups performed the exercise sessions on the same days and were supervised by assistant trainers throughout the experimental period. Although the subjects sometimes participated in recreational sport activity (e.g., rugby, jogging) during the study, all of them were asked to refrain from other resistance training and to keep their normal lifestyle during the experiment.

Muscular strength, endurance, and cross sectional area (CSA) were measured on 3 occasions: 2 weeks (PRE, taken as pretraining in order to minimize the influence of early learning effects on muscular strength), 6 weeks (MID, after the hypertrophy phase), and 10 weeks (POST, after the strength phase) after the beginning of training. One subject in the HC group could not complete the program because of illness and was excluded from the analysis.

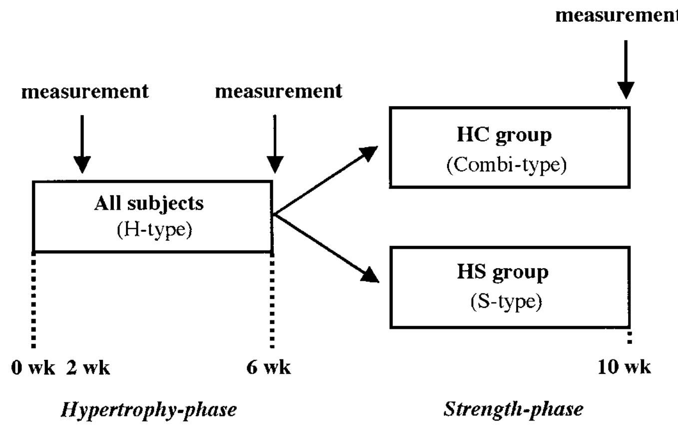

FIGURE 1. Experimental design showing periodization of resistance training and timing of measurements.

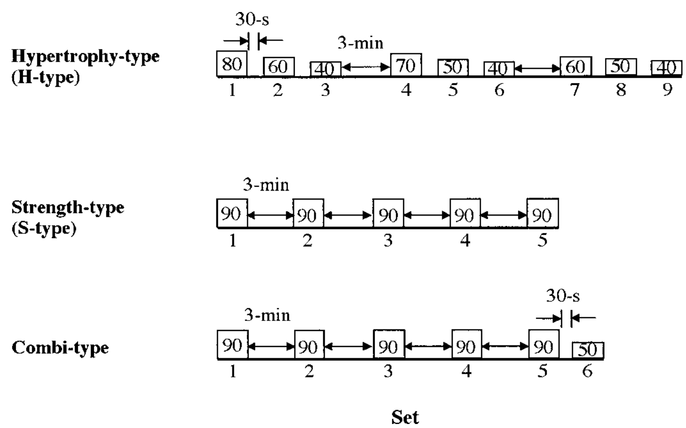

FIGURE 2. Protocols for exercise training. Exercise intensity (% of 1 repetition maxiumum [1RM]) is denoted in each column representing each set.

Subjects

To obtain an insight into the anabolic hormone responses to the hypertrophy-type (H-type), strength-type (S-type), and combi-type regimens, GH responses were initially investigated with 8 male subjects aged 20–23 years (height, 175.0 ± 1.0 cm; body mass, 71.5 ± 2.0 kg). All subjects were undergraduate or graduate students and had a minimum of several months of recreational resistance training experience, but they had not taken part in any regular training program for at least 6 months prior to the beginning of the present study. Also, they had not taken supplements (e.g., amino acid, creatine), anabolic steroids, or other drugs that might affect growth hormone secretion before the study.

Bilateral knee extension was used for the test using the exercise protocols shown in Figure 2. The H-type regimen consisted of nine sets of the exercise at 80–40% of 1RM. The session was divided into three parts with three sets each, and the rest periods between sets and parts were 30 seconds and 3 minutes, respectively. In each part, the intensity was gradually lowered set-by-set (multi-poundage or descending set system). The S-type regimen consisted of five sets at 90% of 1RM with 3-minute rest periods between sets. In the combi-type regimen, subjects completed an additional set of exercise at 50% of 1RM after the last set of S-type regimen, with a 30-second rest period. The combi-type regimen is regarded as a combination of high-intensity (low-repetition) and low-intensity (high-repetition) exercises, the major aim of which is to gain strength. In the additional set, the subjects were instructed to lift and lower the load at a constant velocity and frequency (approximately 40 times per minute). The repetitions in every set of every protocol lasted until the subjects failed to continue the movement. All regimens were performed in a random order with intervals of more than 7 days between regimens.

Measurements of Growth Hormone Response

Venous blood samples were obtained from an indwelling cannula in the antecubital vein before and during the period after each exercise protocol (pre-exercise, 5-, 15-, 30-, and 60-minutes postexercise). Serum GH concentration was measured by standard radioimmunoassay (1) using Kits from Daiichi Radioisotope Lab (Tokyo, Japan). The interassay coefficient of variation (CV) for GH was 3.6%, and the intra-assay CV was 3.4%. The area under the time-GH concentration curve (AUC) above baseline was measured at the range from pre-exercise to 60 minutes postexercise, according to Kraemer et al. (17).

Training Protocol

Leg press and leg extension exercises were performed with normally isotonic machines (Camstar, Hoggan Health Industries, West Jordan, UT). The training regimen for each phase for both groups was the same used and is described in Figure 1. However, the H-type regimen consisted of two parts with three sets (6 sets in total) in this experiment. After a warm up, the subjects performed leg presses and then leg extensions with a rest period of 3–5 minutes between the exercises. The exercise intensity was initially determined as a percentage of 1RM. As the training program progressed, the number of repetitions in each set was controlled day-by-day so as to range from 10–15 RM in the H-type, 3–5 RM in the S-type, and 25–35 RM in the additional set in the combi-type regimen. Therefore, absolute intensity progressively increased throughout the training period.

Measurements of Muscular Strength

Muscular strength of the lower limb was assessed through 1RM of leg press and maximal isometric (maximal voluntary contraction; MVC) and isokinetic strengths (Isok.max) in the knee extension. Before measuring 1RM of leg press, a warm-up with 10 repetitions at 40–50% of the perceived 1RM and stretching of the major muscle groups were performed. The load was progressively increased until the subjects were unable to perform the lift successfully. Three to 5 trials were made in order to establish 1RM.

MVC of unilateral knee extension (dominant side) was measured with a strain gauge attached to a chair. Each subject sat on the chair with his back upright and knee angle kept at 90° and was instructed to exert isometric force as quickly as possible, keeping the maximal force for 3 seconds. The highest value among 3–4 trials was adopted. The maximal rate of force development (RFD) was defined as the maximum slope of the force-time curve (11). The values of RFD were normalized to MVC in order to eliminate the effect of maximal strength on RFD (relative RFD = $[\mathrm{RFD{\cdot}MVC^{-1}}] \times 100$) (24).

Isokinetic strength (Isok.max) of knee extension was measured at 60, 180, and 300 degrees per second with a Cybex Norm 770. Peak torque at the joint angle between 90 and 180° (180° at full extension) was determined from 3–5 trials. A rest period of 2 minutes was allowed between each trial. Intraclass correlation coefficients were $r = 0.92$ for 1RM, $r = 0.84$ for MVC, and $r = 0.86$ for RFD.

Evaluation of Muscular Endurance

Muscular endurance of the lower limb was assessed by measuring the maximal number of repetitions in the leg extension exercise using a normally isotonic machine. The load was set at 30% of MVC determined at the knee angle of 90°. The subjects were instructed to perform the knee extension movements at a frequency of 30 times per minute until failure. Muscular fatigue was defined as the time when the weight ceased to move or the subjects could not maintain the prescribed pace. After the testing, the work volume was determined as load × repetitions.

Measurement of Muscle Cross-sectional Area

The cross-sectional area (CSA) of the thigh was measured using nuclear magnetic resonance imaging (MRI) with a body coil (1.5 Tesla, Gyroscan; Philips Wanchai, Hong Kong). The image acquisition (repetition time 550 ms; echo time 15 ms; field of view 240 mm; matrix 128 × 256; slice thickness 10 mm) was started with the subject lying in a supine position with his legs extended and relaxed. Of the obtained serial sections, one at the midpoint of the thigh (halfway between the trochanter major and head of the tibia) was chosen for analysis. On the selected cross-sectional image, the outlines of the knee extensor (quadriceps femoris; QF) and flexors were traced. Traced images were introduced into a computer (Power Macintosh G3; Sunnyvale, CA) with a scanner (GT-9000, Epson; Suwa, Japan), and their CSAs were measured using NIH Image (ver. 1.61, Bethesda, MD). MVC per CSA of QF ($\mathrm{MVC{\cdot}CSA^{-1}}$) was then determined as an index of neuromuscular function. Intraclass correlation coefficient of the CSA was $r = 0.99$.

Statistical Analyses

Data were expressed as mean ± *SEM*. Statistical evaluation of the data in the experiments on acute GH response and periodized training was accomplished by using a one-way or a two-way analysis of variance (ANOVA) with repeated measures and Fisher's protected least significant difference (PLSD) post hoc comparison, respectively. Percentage changes between HC and HS groups were analyzed using independent t-tests. Statistical significance level was set at $p \leq 0.05$.

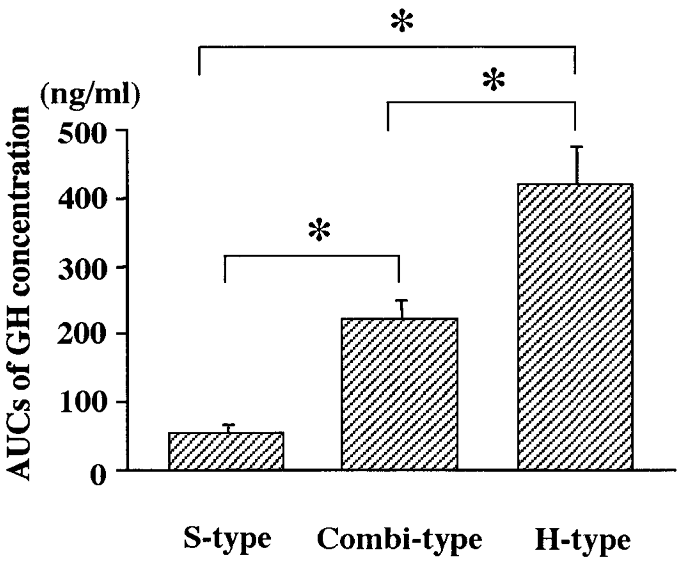

FIGURE 3. Area under the curves (AUCs) in the time course of growth hormone (GH) concentration after 3 types of training regimen. Values are mean ± *SEM*. * = significant difference between regimens ($p < 0.05$).

TABLE 2. Physical characteristics of subjects. Values are mean ± *SEM*.*

Variable	HC group	HS group
Body mass (kg)		
PRE	70.8 ± 4.6	72.6 ± 3.9
MID	70.4 ± 4.3	72.8 ± 3.5
POST	70.5 ± 4.4	72.2 ± 3.4
Body fat (%)		
PRE	18.4 ± 2.2	20.8 ± 1.4
MID	19.2 ± 1.9	20.3 ± 1.4
POST	18.4 ± 2.0	20.3 ± 1.3

* HC = hypertrophy/combi; HS = hypertrophy/strength; PRE = 2 weeks after the beginning of training; MID = 6 weeks after the beginning of training; POST = 10 weeks after the beginning of training.

RESULTS

Acute Growth Hormone Response

Figure 3 shows AUCs of GH concentration after 3 types of exercise. They were significantly higher after the H-type regimen (419.8 ± 56.2 ng·ml^{-1}) than after combi-type (221.5 ± 28.0 ng·ml^{-1}) and S-type (56.1 ± 7.7 ng·ml^{-1}) regimens. Also, AUC after the combi-type exercise was significantly higher than after the S-type exercise.

Effects of Periodized Training

In the second part of the present study, the effects of periodized exercise training with a combi-type regimen on muscular size and strength were examined. No significant differences were seen between the groups in all variables at their baselines.

Physical Characteristics and Muscle Cross-sectional Area

Physical characteristics of the subjects are shown in Table 2. No significant changes were observed in body mass or percentage of body fat at any time points over the training period in HC and HS groups. CSA of the thigh muscles in both groups significantly increased during the hypertrophy phase (Figure 4). During the subsequent strength phase, the CSA showed a further increase in the HC group but not in the HS group. However, the percentage changes of CSA after the strength phase were not significantly different between the groups ($p = 0.08$).

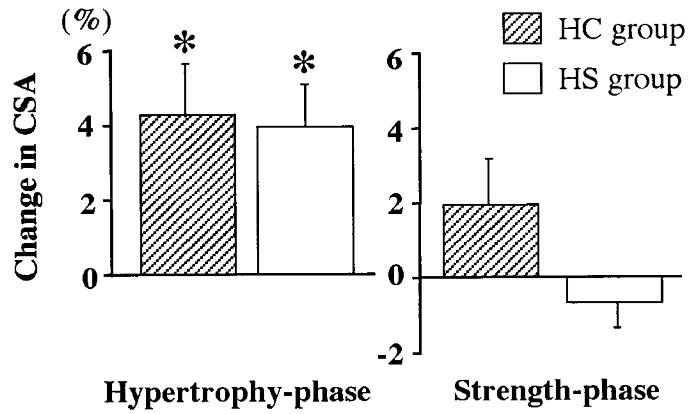

FIGURE 4. Percentage changes in muscle cross-sectional area (CSA) of the thigh after hypertrophy (0–6 weeks) and strength phases (7–10 weeks). Values are mean ± *SEM*. * = significant change from pretraining value ($p < 0.05$).

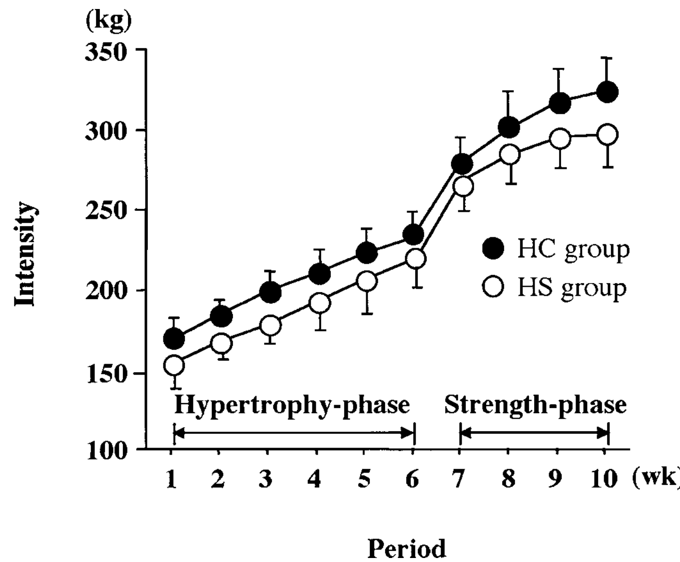

FIGURE 5. Weekly changes in mean exercise intensity of leg press during the training period. The target intensity in every workout was 10–15 repetition maximum (RM) in the hypertrophy phase and 3–5 RM in the strength phase (see "Methods"). Values are mean ± *SEM*.

Muscular Strength and Rate of Force Development

Figure 5 shows the progressive changes in mean exercise intensity of leg press during the training period. The exercise intensity may reflect the 1RM strength, because it was controlled so as to meet the target RM in each exercise session. In both groups, intensity (10–15 RM) constantly increased during the hypertrophy phase. During the subsequent strength phase, the intensity of the major part of the exercise (3–5 RM) appeared to show a larger increase in the HC group than in the HS group. However,

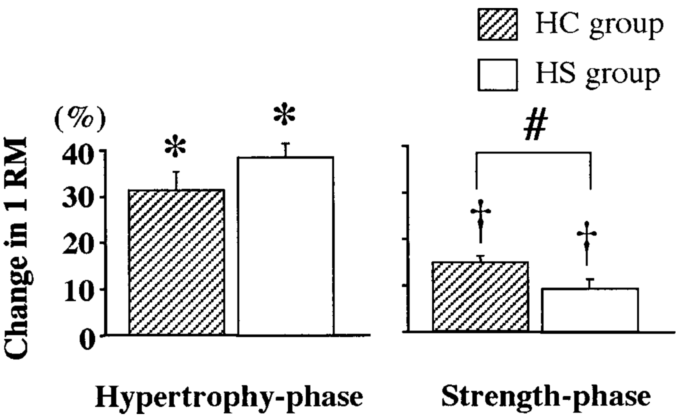

FIGURE 6. Percentage changes in one repetition maximum (1RM) of leg press after hypertrophy (0–6 weeks) and strength phases (7–10 weeks). Symbols denote significant differences ($p < 0.05$) from pretraining (*) and midtraining (†), and between groups (#). Values are mean ± *SEM*.

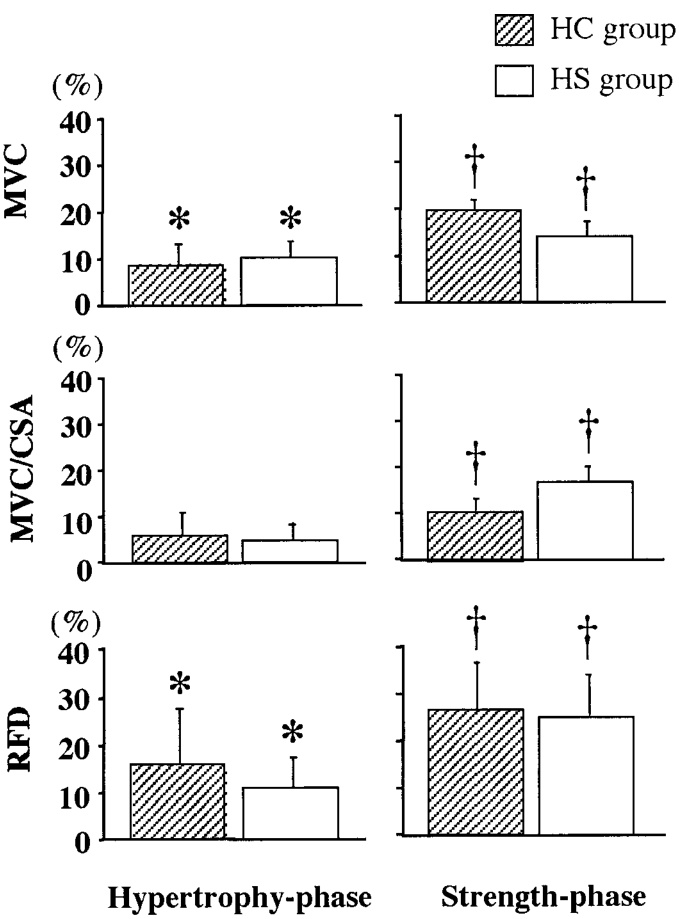

FIGURE 7. Percentage changes in maximal voluntary contraction (MVC), maximal voluntary contraction per muscle cross sectional area (MVC·CSA^{-1}), and rate of force development (RFD) in knee extension exercise after hypertrophy (0–6 weeks) and strength phases (7–10 weeks). Symbols denote significant differences ($p < 0.05$) from pretraining (*) and midtraining (†). Values are mean ± *SEM*.

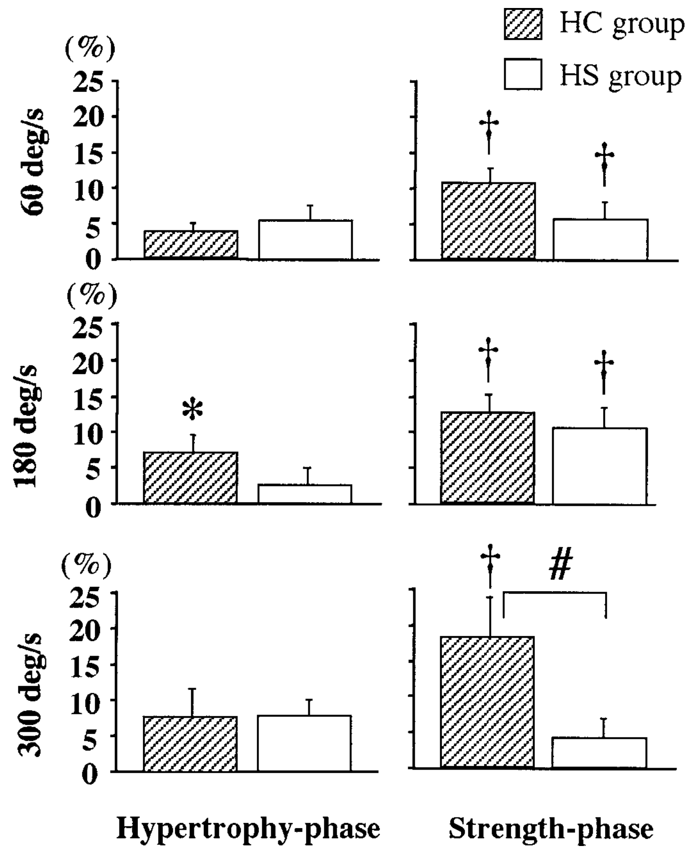

FIGURE 8. Percentage changes in maximal isokinetic strength of knee extension exercise at three different angular velocities after hypertrophy (0–6 weeks) and strength phases (7–10 weeks). Symbols denote significant differences ($p < 0.05$) from pretraining (*) and midtraining (†), and between groups (#). Values are mean ± *SEM*.

no significant difference was seen between the groups throughout the training period. The percentage change in 1RM (Figure 6) showed no significant difference between HC and HS groups after the hypertrophy phase, but it was significantly higher after the subsequent strength phase in the HC group (14.7 ± 1.1%) than in the HS group (9.3 ± 2.0%, $p < 0.05$).

MVC in the unilateral knee extension exercise significantly increased after the period of training in both groups, although no significant difference was observed in its percentage changes between the groups after each phase. In both groups, MVC·CSA^{-1} significantly increased only after the strength phase, although no significant difference was seen between the groups. RFD significantly increased after each period of training in both groups. However, the changes were not significantly different between the groups (Figure 7). The same result was obtained when RFD was normalized to MVC (RFD·MVC^{-1}).

Isok.max tended to increase at all angular velocities measured after the hypertrophy phase, but the changes were not significant except at 180 degrees per second in the HC group (Figure 8). After the subsequent strength phase, Isok.max significantly increased in both groups except at 300 degrees per second in the HS group. At this

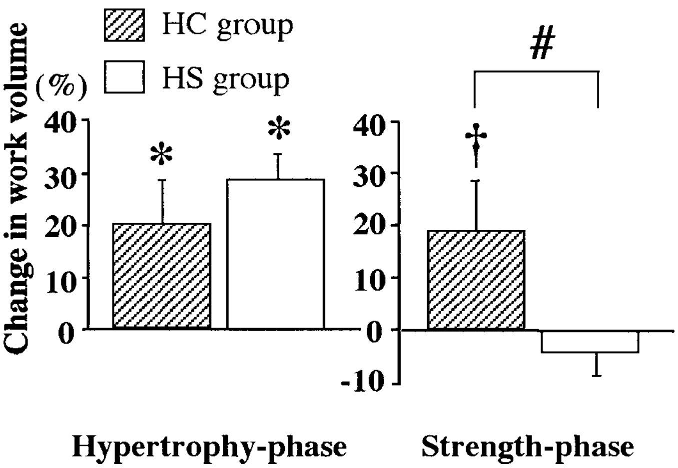

FIGURE 9. Percentage changes in work volume in knee extension exercise with the load corresponding to 30% of maximal isometric strength after hypertrophy (0–6 weeks) and strength phases (7–10 weeks). Symbols denote significant differences ($p < 0.05$) from pretraining (*) and midtraining (†), and between groups (#). Values are mean ± *SEM*.

velocity (300 degrees per second), changes in strength were also significantly different ($p < 0.05$) between the groups (HC group, 18.2 ± 5.8%; HS group, 4.2 ± 2.4%).

Muscular Endurance

As shown in Figure 9, muscular endurance assessed by the work volume performed in the knee extension exercises improved significantly in both groups after the hypertrophy phase. After the strength phase, however, the work volume showed a further increase from the level after the preceding hypertrophy phase only in the HC group. Changes in the work volume during the strength phase were also significantly different ($p < 0.05$) between the groups (HC group, 18.8 ± 9.4%; HS group, −4.7 ± 5.8%).

DISCUSSION

In the present study, HC and HS groups performed the H-type regimen during the first 6 weeks. This type of regimen is characterized by moderate exercise intensity with limited rest periods between sets (18) and is effective in inducing muscle hypertrophy and improvements in muscular endurance, oxidative enzyme activity, and capillary density (4, 21). The present study consistently showed significant increases in muscle CSA and muscular endurance in both groups after the hypertrophy phase (Figures 4 and 9). One RM of leg press and MVC of knee extension also significantly increased (Figures 6 and 7). In addition, no significant difference was seen in the percentage change of any variable between the groups, indicating that the same H-type protocol was appropriately conducted in both groups and the same effects were obtained.

One of the major findings of the present study was a larger increase in 1RM of leg press in the HC group than in the HS group after the strength phase, when different training regimens (combi-type vs. S-type) were used (Figure 6). This suggests that the combi-type regimen caused a larger increase in dynamic muscular strength than did the S-type regimen when combined with the H-type regimen in a periodized fashion. In the present combi-type regimen, a single set of low-intensity, high-repetition exercise (approximately 40–50% of 1RM, 25–35 repetitions) was added to the S-type regimen (5 sets at 90% of 1RM). This effect appears to be inconsistent with the classical principle operating in resistance-exercise training, in which low-repetition protocols are used for muscular strength, and low-intensity, high-repetition protocols are used for muscular endurance (2, 5). Sensible combinations of high- and low-intensity protocols may therefore be more important to optimize the strength adaptation to resistance training.

Increases in Isok.max during the strength phase also tended to be larger in the HC group than in the HS group, and a significant difference between these groups was seen at the velocity of 300 degrees per second (Figure 8). This indicates that the combi-type regimen was effective in improving not only maximal strength but also muscular power at relatively high speeds. Although the reason for this is unclear, the movement during the exercise in the additional set was likely associated with ballistic actions because the load was relatively light (40–50% of 1RM). When the exercise was performed with countermovements, the peak force produced during the exercise was shown to be much larger than the resistance actually applied (25). Thus, such an effect may cause an improvement of muscular strength at high velocity.

Muscular endurance was assessed by measuring the amount of work done in the knee extension exercise. Holloszy et al. (14) have shown that low-resistance, high-repetition exercise is effective in improving muscular endurance. In fact, the H-type regimen with relatively high repetitions (10–15 repetitions) resulted in a marked increase in muscular endurance (Figure 9). In the strength phase, however, while the muscular endurance in the HC group was significantly improved from that after the hypertrophy phase, it tended to decline (not significantly) in the HS group. This suggests that muscular endurance tends to be unchanged or even decline when the training protocol is shifted from hypertrophy- to strength-type regimens.

After the strength phase, the percentage increase in CSA was higher in the HC group than in the HS group, although it was small in magnitude (Figure 4). This suggests that muscular protein synthesis can be facilitated by performing a single set of low-intensity, high-repetition exercise immediately after a high-intensity, low-repetition exercise (S-type). On the other hand, according to the established theory of training, low-intensity, high-repetition exercises are, for themselves, not expected to increase muscular strength, power, or CSA (2). It has been thought that an intensity lower than 65% of 1RM is not substantially useful for gaining muscular size and strength (23). Moreover, Campos et al. (3) have recently demonstrated that 2 sets of exercise at low-intensity (20–28 RM with 1-minute rest periods between sets) did not cause muscle fiber hypertrophy after an 8-week period of training. Although the exact mechanism underlying the present effects of a combi-type regimen remains unclear, we speculate that the increase in blood GH concentration observed in the acute experiment (Figure 3) plays at least a part. However, this interpretation of the circulating of GH needs much precaution, because the circulating has been shown to contain a considerable amount of nonactive forms (i.e., non 22-kDa GH) (9).

We found it important to also examine whether neuromuscular adaptation was suppressed by adding a low-intensity, high-repetition exercise in the combi-type regimen. Motor-unit recruitment patterns have been shown to differ between high-intensity resistance exercise and low-intensity endurance exercise (19). In addition, Tamaki et al. (26) have demonstrated that low-intensity, high-repetition exercise sometimes hinders improvements of muscular power and speed, because this type of exercise tends to make contractile property slower. Thus, we measured MVC per muscle CSA (MVC·CSA^{-1}) and RFD as indicators of neuromuscular activity (15). MVC·CSA^{-1}, RFD (Figure 7), and RFD normalized to MVC showed similar increases in both groups after the strength phase, suggesting that an additional set of low-intensity, high-repetition exercise did not cause an undesirable effect on neuromuscular activity.

At present, we cannot exclude the possibility that the greater effects of the combi-type regimen are due, at least partially, to its greater training volume than that of the S-type regimen. To solve this problem, experiments with more precisely controlled volumes should be conducted. In addition, the differences in the effects between the groups were not always large, with no significant difference in some parameters (e.g., MVC, Isok.max at 60 and 180 degrees per second, CSA). The period of 4 weeks for the strength phase may be slightly short to reveal marked differences in its effects between the groups. Despite these limitations, the present results suggest that an additional set of low-intensity, high-repetition exercise is practically important and useful in periodized training programs.

The combi-type regimen caused a larger increase in serum GH concentration and larger gains in muscular strength and endurance than those caused by the S-type regimen. This effect may be specific to a single set of low-intensity exercise added immediately after a high-intensity and low-repetition exercise. These results suggest a new strategy for the exercise prescription during the neural adaptation phase (strength phase) of a periodized training program. Due to several limitations in interpreting the present results, however, investigations with more strictly controlled exercise volumes, longer training periods, and larger numbers of subjects are to be conducted to establish the effectiveness of the present combi-type regimen. The regimen's mechanism needs further elucidation, as well.

PRACTICAL APPLICATIONS

Periodization in exercise training has become more important in strength and conditioning (20). A typical periodized program begins with a high-volume and low-intensity protocol (hypertrophy phase), and then proceeds to a low-volume and high-intensity protocol (strength phase) (6). The present results demonstrated the effects of an additional set of low-intensity exercise immediately after a high-intensity, low-repetition exercise in gaining muscular strength and endurance, suggesting its usefulness in the strength protocol. Although the precise mechanism for its effects remains unclear, the present regimen with combined high- and low-intensity resistance exercises may be useful, at least occasionally, in various kinds of sports that require muscular strength and endurance simultaneously.

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