Early plateaus of power and torque gains during high- and low-speed resistance training of older women

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Signorile, Joseph F., Michelle P. Carmel, Shenghan Lai, and Bernard A. Roos. Early plateaus of power and torque gains during high- and low-speed resistance training of older women. J Appl Physiol 98: 1213–1220, 2005; doi:10.1152/japplphysiol.00742.2004.—Periodization is the most effective approach to resistance training; however, optimal cycle lengths for older persons are not known. This study examined the durations of performance incre-
ments, plateaus, and decrements in women, ages 61–75 yr, over 9 wk of isokinetic training. After a 2-wk adaptation cycle, older women trained for either power (PWR; 4.73 rad/s; n 9) or strength (STR; 1.05 rad/s; n 8), 3 days/wk with a 1-day recovery between sessions. Repetitions were initially selected to equilibrate work volume between groups. Average power (AP), peak torque (PT), and total work (TW) curves were analyzed using forward and backward stepwise regression to ascertain inflections and plateaus. PWR training produced the highest AP, whereas STR produced the highest PT. TW was similar between groups. The AP curves of the PWR group initially showed a steep positive slope and then plateaued during week 3. The right leg plateau lasted throughout training, whereas the left leg showed another positive inflection during weeks 7 and 8. PWR group TW curves showed positive slopes throughout training. STR group PT curves for both legs showed initial positive slopes peaking between weeks 3 and 4 and declining thereafter. The TW curves for both legs showed slight negative slopes across the first 2 wk, steep positive slopes during weeks 3–6, and a final plateau. Because improvements plateau early during PWR and STR training, isokinetic training prescriptions for optimizing strength and power improvements in older persons should use cycles of 3–4 wk to maximize gains.

Resistance training can be an effective short-term intervention to counteract the strength (6, 14, 18) and power (15, 33, 56, 57) losses resulting from sarcopenia. However, studies incorporating training periods longer than 6 mo have reported declining gains after the initial 2–3 mo of training (42, 43, 51, 52). To our knowledge, no studies have examined the daily performance changes during the initial 8 wk of a resistance-training program. The patterns of change in both intensity and volume during the first 8 wk of training are important because maximal strength and power gains during resistance training cannot occur unless the training cycle includes periods of recovery or taper (3, 46). Therefore, periodization programs are designed to include periods of taper that gradually reduce the volume and intensity of training to allow recovery and subsequent increases in performance (4). In fact, periodization has been proven more effective than standard progressive resistance protocols at increasing strength and power (12, 48, 60), and taper has increased both neuromuscular (24, 25) and cardiovascular (32, 38, 41) performance when incorporated into a training cycle. Moreover, alternating cycles of overload and recovery can reduce the incidence of overtraining syndrome (23), decrease injury levels (13, 58), improve training efficiency (35), increase neuromuscular gains (24, 25), and enhance exercise compliance (5). In addition to providing alternating cycles of work and recovery, periodization can also incorporate diverse training cycles targeting specific goals such as strength, power, or endurance. For example, maximal strength gains require high levels of resistance (27), whereas power is better addressed using moderate loads (30–50% of maximal) and higher contractile speeds (34, 61). Unfortunately, there are no current data
indicating the proper cycle lengths to maximize strength and power gains in older persons, and the cycle lengths currently recommended for younger persons and athletes (1, 3) are unlikely to apply to an older population. Therefore, the primary purpose of this study was to examine the time course of improvements, plateaus, and declines during an initial 9-wk isokinetic resistance-training cycle of the knee extensors with previously untrained older women and to use peak torque (PT), average power (AP), and total work (TW) as markers of strength, power, and volume, respectively. Because we hypothesized that performance decrements would occur during the 9-wk training cycle and that changes in intensity (AP and PT) would affect, and be affected by, changes in TW, we also examined how PT and AP measures changed relative to TW to ascertain the temporal relationships between intensity and volume during strength and power training. We considered this relationship especially important because maintaining intensity during a taper is thought to be imperative to maintain improvements achieved during training (28). Finally, we compared mean AP and PT values throughout the training period to confirm that high-speed training specifically targets AP, whereas low-speed training targets PT.

Although the patterns of change during isokinetic and isoinertial training may not be the same, studies have found a strong relationship between isokinetic and isoinertial testing results (31, 47), and these two testing methods presented statistical generality across a 12-wk training program (2). In addition, isokinetic training models have been previously used in time-course analysis studies where control of movement speed and power were considered important factors (9, 59). For our study, the isokinetic training model enabled us to control movement speed while we observed changes in torque, power, and TW as markers of intensity and volume of training across time. Finally, recent data from exercise interventions for patients with osteoarthritis indicate that isoinertial training may be the preferred method of improving strength during the early stages of a resistance-training intervention, but isokinetics may be more effective in improving joint stability and walking endurance over a longer time period (30).
MATERIALS AND METHODS

Subjects. Seventeen women, ages 61–75 yr, participated in this study. All subjects were living independently in the community, and no subject had resistance trained within the past 3 yr. Subjects filled out a comprehensive medical disclosure form. No subject reported neuromuscular or metabolic conditions that would have negatively affected her participation in the study or her ability to perform the exercise prescriptions. Subjects were fully informed of all procedures and signed an informed consent before beginning the study. All procedures were approved by the University of Miami Subcommittee for the Use and Protection of Human Subjects.

Experimental design. Subjects’ baseline PT, AP, and TW values for the left and right legs were assessed on a Biodex dynamometer (Biodex, Shirley, NY) before the training program began, and they were matched using age and isokinetic knee extension PT values at 3.14 rad/s. This speed was chosen because it is intermediate between our high-speed power and low-speed strength-training conditions and because it has been used as the intermediate training and testing speed in a number of other studies on speed-specific training (10, 55, 56). The subject was positioned according to the setup procedures outlined in the Biodex manual. To reduce the impact of accessory muscles, Velcro restraining straps were placed diagonally across the shoulders and across the waist and thigh. The leg was secured to the Biodex arm with a padded Velcro strap. The pad was placed immediately inferior to the heads of the gastrocnemius, and the axis of the dynamometer was aligned with the lateral femoral condyle.

Before being tested, subjects were given a number of practice trials at 1.57, 3.14, and 6.28 rad/s to make them familiar with the concept of isokinetic testing and the speed-specific nature of a maximal effort. Subjects were then allowed a 3-min recovery period before actual testing began. After recovery, the subject was allowed a five-repetition warm-up at 3.14 rad/s using a perceived exertion of 50% of maximum. The warm-up was followed by a 1-min recovery before the actual testing. Three maximal efforts were performed. Verbal encouragement was offered during all efforts. If a subject did not provide maximal effort throughout the three repetitions, as evidenced by a large disparity among the testing curves, the test was repeated after a 3-min recovery period. The calibration of the Biodex dynamometer was confirmed on both the morning and afternoon of each testing day. No significant differences were found between pretest values for the right and left legs. In addition, all subjects were right handed. Given the lack of significant difference between legs and the reported correlation between hand and leg dominance (7), we chose to use right-leg PT values to match the subjects. Once matched, subjects were randomly assigned to a high-speed power-training group (PWR) or a low-speed strength-training group (STR) using a simple coin toss. Table 1 shows the mean ages, weights, and heights for the PWR and STR groups. Because the purpose of the study was to trace patterns of change in PT, AP, and TW values during isokinetic training, only training groups were included in the analysis.

Training. The reliability of isokinetic evaluations of strength and power in older subjects has been well established (17). Our study also utilized only one technician, with more than 2 yr of experience, to provide the training during all sessions. Both the PWR and STR groups trained their knee extensors three times per week for 12 wk on
the Biodex dynamometer using the same setup and warm-up procedures described for the initial testing session. We chose isokinetic dynamometry as a training methodology because it allows precise control of training velocity while providing complete information on PT, AP, and TW throughout the training period. Resistance during isokinetic training is dictated by the individual’s ability to meet the speed setting of the dynamometer; therefore, low-speed isokinetic training provides higher resistance and a greater strength stimulus, whereas high-speed training has greater impact on movement speed and power. In addition, all efforts during isokinetic training are at perceived maximum; therefore, PT and AP data can be used to quantify changes in the intensity of the strength and power cycles, respectively, whereas TW data can be used to evaluate work volume for each training day. Thus we could assess the relationship between intensity (PT and AP) and volume (TW) across the training cycles and examine patterns of change in intensity and volume as the subject attempted to produce a maximal performance. We could also determine the optimal cycle lengths for both the strength and power training cycles based on the changes in each variable. Both the right and left legs were trained. Subjects were instructed to perform all repetitions as rapidly and forcefully as possible. The PWR group did 10 repetitions at 4.73 rad/s, whereas the STR group did 6 repetitions at 1.05 rad/s so that their initial TW equaled that of the PWR group. Isokinetic data collected earlier from 104 community-dwelling men and women, 62–78 yr of age, were used to establish the number of repetitions necessary to equilibrate work between groups (56). Data from our laboratory have also shown that knee extensor power continues to increase in this population up to an isokinetic speed of 5.25 rad/s; therefore, 4.73 rad/s was well within the training range for these individuals (55). In addition, movement speed, rather than force production, has been shown to be the major determinant of instantaneous power in older women (11). Because our study was designed to examine patterns of change, rather than end-point values, across multiple training sessions, setting up a control group was not feasible; a regular pattern of multiple repetition testing of a “control” group would have constituted training. During the first 2 wk of the study, TW was gradually increased to allow tissue adaptation and reduce the level of delayed-onset muscle soreness commonly associated with maximal-effort training. Table 2 shows the patterns of volume and intensity change for the tissue-adaptation period. Although both groups started at the same work volume, the STR group increased its work volume more rapidly than the PWR group, as indicated by the initial TW values for each group on the first day of week 3. During the final week of training, TW was gradually reduced to allow recovery (taper) before posttesting. Because the research protocol rather than the subjects’ performance governed the volume, these data were not included in the time-course analysis. Pretest and posttest data were not considered part of the analysis of time-course changes during training and have been reported elsewhere (55).

**Statistical analysis.** Means and standard deviations were computed for AP, PT, and TW produced by the right and left legs during PWR and STR training. As noted earlier, the tissue-adaptation phase was not included in the time-course analyses because it did not represent Table 1. **Physical characteristics of subjects**
Values are means
SD. PWR, power-training group; STR, strength-training group; Sample, PWR and STR groups combined.

RESISTANCE TRAINING CYCLES IN OLDER WOMEN

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a period of imposed change dictated by the stress of the training stimuli. A repeated-measures analysis was used to detect differences in AP, PT, and TW between right and left legs and training groups. When a significant leg group interaction was detected, a Bonferroni least squares means post hoc test was used to detect significant differences among the means of these variables.

Scatterplots showing the daily values for AP, PT, and TW across the 9-wk training period were first examined visually for inflections or plateaus. We then used regression lines, derived from Spline and Friedman smoothing techniques, to improve visualization. Finally, a two-stage linear regression technique was performed using the data from the days preceding and after each visual inflection point to establish the actual point of inflection. First, the forward stepwise regression started with the initial 7 training days and continued through the data of the last day. Next, the backward stepwise analysis started with the data from the last day and worked forward. The correlation coefficients ($R^2$ values) for each of the lines were continuously computed as the data points for each day were added to the analysis. An inflection point was the point where the $R^2$ value was among the highest seen during the forward stepwise regression and the lowest seen for the backward stepwise equation. This point had a large impact on the fitting of the initial regression line but little impact
on the equation for the second fitted line. Where two inflection points appeared, the analysis was repeated for each visible inflection in the curve, with the forward stepwise regression beginning at the previous inflection point.

RESULTS
Repeated-measures ANOVAs revealed a significant group leg interaction for AP ($P<0.0001$), PT ($P<0.0001$), and TW ($P=0.0439$) produced across the training period. Table 3 shows the results of the Bonferroni post hoc analyses used to detect significant differences in these variables by group and leg. As Table 3 indicates, the PWR group produced a significantly higher mean AP than the STR group across the 9-wk training cycle ($P<0.0001$). In contrast, the STR group produced significantly higher mean PT than the PWR group ($P<0.0001$). TW showed no significant difference between groups. As Table 3 shows, the right (dominant) leg produced significantly greater mean AP, PT, and TW than the left leg across the training cycle of the PWR and STR groups.

The right and left leg AP curves for the PWR group (Fig. 1, A and B) were similar in shape throughout the initial 6 wk of training, although they varied slightly in magnitude. The slopes of the regression lines produced by the stepwise analyses show nearly parallel rates of improvement (6 W/wk) during the first 3 wk of training. Both curves then showed a prolonged plateau beginning during training week 3. The plateau for the right leg lasted for the duration of the training period, whereas the left leg produced a second positive inflection during week 7. Both the right (Fig. 1C) and left (Fig. 1D) legs of the PWR group showed a continuous increase in TW across the first 6 wk of training (25 kJ/wk). For the left knee, this pattern of increase lasted throughout the training period, whereas the right knee showed a reduced rate of improvement starting at week 7 and lasting for the duration of the training.

For the STR group, both the right and left legs produced a bell-shaped PT curve (Fig. 2, A and B). Rates of improvement for the right and left legs were similar during the initial portion of the training curves (1–1.5 kg-m/wk). By weeks 4 and 5, respectively, the training curves for the right and left legs showed a gradual decline that approached week 1 levels by the end of the training period. The TW curves for both legs of the STR group were also very similar (Fig. 2, C and D). The right and left legs showed initial TW declines that lasted into training week 2. Both curves then showed a sharp incline (10–15 kJ/wk) followed by a final plateau lasting the remainder of the training period. The plateaus for both legs began during training week 5.

DISCUSSION
The major result from our study of intense resistance training in previously untrained older women is that gains in PT and power leveled off early (at 3–4 wk) in the training cycle. Our data also show that progressive increases in intensity and volume led to declines in performance and that the reciprocal
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| 3 | day before |
| PWR | testing |

Table 3. Results of repeated-measures analysis of group and leg AP, PT, and TW values across the training period.

Group
Leg
PWR
STR
P value
Right
Left
patterns of change between intensity and volume differ during PWR and STR training. Finally, our data confirm the results of previous studies in older persons showing that high-speed, low-load training targets power improvement, whereas low-speed, heavy-resistance training increases strength (55).

**Training specificity.** The fact that the PWR group produced their greatest gains in AP whereas the STR group showed their greatest gains in PT can be attributed both to the nature of the isokinetic stimulus and the joint action trained. Isokinetic dynamometers use changes in resistance to control movement speed (50). Therefore, our PWR training protocol, performed at 4.73 rad/s, was expected to provide the velocity-based overload commonly used to increase power (27, 34, 61). In contrast, the lower speed setting used during STR training (1.05 rad/s) provided greater resistance and therefore a greater impact on torque production (26, 37).

Our findings are supported by a study indicating that movement speed, rather than force production, is the major determinant of instantaneous power in older women (11) and by our recent work showing that the knee extensors, but not the knee flexors, dorsiflexors, or plantar flexors, can reach the training
speeds necessary to elicit significant increases in power (55). The results of this study also confirm previous findings by our group and others that power is more effectively increased using lower loads and higher training speeds, whereas strength is better addressed using high-load, low-speed training in both younger (26, 36, 37) and older (14, 18, 55) persons.

Patterns of change during strength and power training cycles. As noted earlier, periodized training uses variations in volume and intensity to reduce the incidence of overtraining syndrome (23), decrease injury (13, 58), improve training efficiency (35), increase neuromuscular gains (24, 25), and enhance exercise compliance (5). Training tapers lasting a 4- to 14-day period have also positively impacted strength and power improvements (24, 25, 32, 41). In addition, variations in the nature of the training stimulus appear to have a significant impact on fatigue and recovery after a training cycle (20, 39).

The simultaneous increases in AP and TW during the first 3–4 wk of training indicate that our subjects were able to tolerate the low-load, high-velocity training associated with our PWR training protocol with minimal decreases in performance. This result agrees with studies showing no significant performance decrements during the early stages of light- to moderate-load resistance-training regimens (20, 39). Our data do show, however, that by the third week of training further increases in TW were at the cost of further increases in intensity (AP). Because our training model required subjects to complete all sets and repetitions, and because all repetitions were performed at the subjects’ perceived maximums, a logical interpretation of these data is that the subjects’ capacity to increase TW after training week 3 required an involuntary reduction in training intensity (AP) dictated through either central or peripheral fatigue mechanisms.

The relationship between training intensity and volume can also be seen by examining the PT and TW curves for the STR group. These data show that increases in PT at the onset of training were at the cost of TW. Apparently, high-resistance/low-velocity STR training required subjects to reduce their training volume (TW) to increase intensity (PT) across the first 2 training wk, even after the 2-wk tissue-adaptation period. Between weeks 2 and 6, increases in volume (TW) became apparent. Both curves then plateaued for the remainder of the study, with the right and left legs showing slightly negative and positive slopes, respectively. The associated PT curves showed positive slopes until training week 4 and a subsequent decline.
to near baseline levels by the end of training. These data indicate that even after a 2-wk tissue-adaptation period, in which training volume was gradually increased, the women in our study could not adjust to the high loads associated with STR training without reducing training volume (TW). In addition, once the volume of work began to increase, the intensity progressively declined until the end of training. By the end of week 6, TW had plateaued even in the face of declining PT, showing that the women could no longer maintain either volume or intensity using the high-resistance STR overload. The results described in the previous paragraph are similar to those reported previously using isoinertial training, and the mechanisms causing the concurrent AP and TW patterns during PWR training and PT and TW patterns during STR training may be similar to those presented in these studies. Linnamo et al. (39) examined the levels of neuromuscular fatigue in eight men and eight women randomly assigned to either maximal strength training [MSL; 10 repetitions maximum (RM)] or explosive strength training (ESL; 40% of 1 RM) on different days. Both protocols used the same number of repetitions, sets, and training sessions. As was the case in our study, these researchers reported different fatigue patterns for each training protocol. They reported that decreases in force production were greater and recovery times were longer after MSL compared with ESL. They also noted higher lactate accumulations after MSL vs. ESL. Although integrated electromyographical activity during the initial 100 ms of each contraction declined more during ESL, the integrated electromyographical activity declines during the prolonged 500- to 1,500-ms portion of the contraction were greater during MSL. The researchers suggested that these differences might have been related to greater peripheral fatigue produced by the higher load MSL protocol and greater central fatigue generated by the lower resistance ESL protocol. Similar fatigue mechanisms may explain the differences seen in the AP, PT, and TW curves produced by the PWR and STR groups in our study. For example, we saw an initial rise in both AP and TW during the first 3 wk of PWR training, whereas TW declined during the initial weeks of STR training. This pattern reflects the conclusions by Linnamo et al. that explosive low-load movements seem to facilitate neuromuscular function rather than cause fatigue.

The unique fatigue patterns resulting from different training protocols were also examined in a study by Fry et al. (20). One protocol employed high-load, low-volume training (10 one-
repetition sets at 100% 1 RM), whereas the other employed low-volume, low-load training (1 set of 5 repetitions at 32 kg, 1 set of 5 repetitions at 40% 1 RM, and 3 sets of 5 repetitions at 50% 1 RM). The researchers reported that, by training week 3, significantly greater 1-RM decrements were observed in the high-load vs. low-load group. They also reported greater reductions in isokinetic and stimulated isometric force production during high-load training, attributing the differences to greater peripheral fatigue and acute muscle damage.

In a follow-up study (21) using the same training protocols, these researchers quantified epinephrine and norepinephrine levels across a 3-wk training period. After training, their high-load group required significantly greater catecholamine levels to achieve the pretraining work levels. They concluded that the higher load protocol caused a downregulation of the 2-receptors of the working muscles and that greater catecholamine levels were required to elicit the same contractile response. Finally, a number of researchers have noted the impact of training volume (49) and intensity (22) on mood states and associated performance in athletes. In fact, Morgan et al. (44) reported a dose-response relationship between increases in training stimulus and declining mood states.

Although we did not measure the hormonal, electromyographical, or psychological responses to our STR or PWR training protocols, given the similarities between our training protocols and those cited earlier, an attractive hypothesis is that the divergent performance responses produced by each of our protocols were attributable to fatigue mechanisms similar to those reported in the cited studies.

Although other responses such as cortisol-to-testosterone ratios, growth factor expression, and immune system changes have been reported with overtraining syndrome (staleness), these responses vary greatly according to type of overload, training protocol, and testing methodology and do not seem to be as pronounced with resistance-training protocols as they are with endurance training (19, 22).

Our data suggest that high-resistance, low-speed STR training produced a greater level of stress than low-resistance, high-speed PWR training. Reductions in performance may be the combined result of a fitness effect and a fatigue effect, and in our study it appears that at the onset of training the fitness effect predominated in the PWR group, whereas fatigue dominated in the STR group. By the fourth week of training, however, increases in volume were always accompanied by reductions in intensity regardless of the training protocol. As noted above, intensity is the major factor dictating performance enhancements during both training and taper. Therefore, our data indicate that, for training intensity to be maintained in older women during the taper period, reductions in the volume of training should begin by the third or fourth week of isokinetic training.

Further research, using longer training periods and diverse training cycles, is needed to determine what differences in volume and intensity patterns might be seen across a periodized training regimen. Additionally, similar studies using
isoinertial training could determine whether these time-course changes hold true under different contractile conditions. Finally, given the importance recently placed on high-speed, low-resistance training to improve power and contractile speed in older persons (15, 33, 55, 56), studies should examine changes in performance, integrated electromyographical activity, and hormonal levels with both high-load and high-velocity overload to determine the relative impacts of each of these factors during training.

We and other researchers have found that the greatest rate of improvement occurs during the initial portion of a training period (42, 43, 51, 52). These findings differ in part from those reported in two studies by McCartney et al. (42, 43), who found continued increases in training across a 2-yr resistance-training program with men and women 60–80 yr old. However, the different findings may be explained by a number of factors. The first is the contrasting nature of the data collected. In both of their studies, McCartney et al. reported data collected during testing sessions designed to elicit maximal isoinertial 1-RM performances. The assessments followed a 1- or 2-day recovery period and reflected the best single lift recorded during two testing sessions separated by 24 h. In contrast, our data were collected during the actual training sessions and described the efforts made by the subjects during multiset, isokinetic training.

The second differentiating factor between these studies was the sampling frequency and duration. Our data were collected during every training session over a 9-wk training cycle. McCartney et al. (42, 43) collected data during separate testing sessions performed once every 6 wk. In comparing their data with differing results from other groups, McCartney et al. (43) noted that their more frequent data collection (every 6 wk) might have allowed them to detect transient changes missed by studies that tested less frequently. Sampling during every session may have allowed us to detect changes in training adaptations that would not have been evident with less frequent sampling such as the 6-wk cycle used by McCartney et al. (42, 43).

Other factors that may have contributed to the contrasting findings in these studies are the higher training intensity (maximal speed-dictated loads vs. submaximal loads) and frequency (3 sessions vs. 2 sessions per week) of our program and the periodic increases in intensity during their study (every 6 wk) compared with the performance-dictated changes for each repetition during our training program.

Factors such as the nature of the training, sampling frequency, duration, intensity, and frequency of training and the rate at which intensity, volume, and duration change during training may all affect performance improvements and fatigue during training. Thus the sampling techniques we used would be advantageous in assessing changes during long-term resistance-training studies in older persons, where the goal is to ascertain daily variations in training performance so that training cycles can be adjusted to maximize performance gains.
Conclusions. The findings of this study support the following recommendations for the initial cycles of isokinetic training in older women. First, cycles may be designed to target strength or power by applying low-speed (high resistance) or high-speed (low resistance) training, respectively. Second, the patterns of loading during these training cycles should vary depending on the goal of the training and the nature of the overload dictated by that goal. When targeting strength with a low-speed/high-resistance protocol, it may be important to incorporate a prolonged, gradual tissue-adaptation period into the cycle to reduce initial fatigue or even to incorporate a taper period between the initial adaptation and strength-training periods so that intensity levels can be increased without initial reductions in volume or negative overtraining effects. This is especially important given the strong neurological component early in training (45). In addition, by the fourth week of training, training volume should be reduced during both power and strength cycles so that intensity [the primary factor dictating gains in strength and power (25, 46)] can be maintained or increased during this tapering period. During the tapering period, when the volume of high-intensity training is being reduced, lower intensity motor skill training targeting variables such as balance, mobility, and agility can be used to “translate” physiological improvements into improvements in activities of daily living and instrumental activities of daily living. This recommendation is supported by research indicating that improvements are specific to both skill (29, 40, 53, 54) and movement speed (8, 10), and it reflects the successful models used in all sports in which gains made in the training room are translated into success on the field or court through skills practice. Finally, the recognition of functional need and the application of proper training require analysis of needs (16). Thus diagnostic tests should follow each translational recovery period so that an appropriate training prescription can be applied during the subsequent training cycle as the subject responds to the specific overload applied.

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