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Autoregulation by "repetitions in reserve" leads to greater improvements in strength over a 12-week training program than fixed loading

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ABSTRACT

Autoregulation (AR) of training involves altering resistance session parameters based upon the athlete's readiness to train. One potential benefit of AR may be that training intensity can reflect an athlete's increasing strength level throughout a training program, and can be contrasted with fixed loading (FL) where the load is stipulated at the start of the program. In this study, 31 resistance trained males participated twice weekly in an AR or a FL squat program. For the FL group load was prescribed as a percentage of the pre-test one repetition maximum whereas for the AR group load was prescribed based upon the number of "repetitions in reserve", such that the intensities were theoretically the same (volume was also matched). Both groups showed a significant increase in front (FS) and back (BS) squat performance, but the magnitude of this was significantly greater for the AR program (FS: AR +11.7%, FL +8.3%, $p = 0.004$, $\eta_p^2 = 0.255$; BS: AR +10.8%, FL +7.1%, $p = 0.006$, $\eta_p^2 = 0.233$). The AR group trained at a greater intensity (average weekly intensity; FS: AR 83.2 ± 13.3%, FL 80.4 ± 10.0%, $p < 0.001$, $\eta_p^2 = 0.240$; BS: AR 83.6 ± 12.7%, FL 80.4 ± 10.0%, $p = 0.006$, $\eta_p^2 = 0.159$). The results of this study support the contention that AR can be used to accommodate the increasing strength level of the athlete during the course of a program and that such a strategy is effective in eliciting greater strength adaptations across 12 weeks.

KEY WORDS: strength training, RIR, squat, block periodization, readiness to train

INTRODUCTION

Maximal strength is an essential component in optimising athletic performance and has been demonstrated to enhance sports such as endurance running, soccer and sprint cycling (2, 5, 23, 24). It is generally accepted that periodized programming is more effective in eliciting strength gains than non-periodized training (15, 16). Periodization is defined as the planned distribution of training to increase the potential for achieving optimal sports performance at a predetermined time point (20). One such method of periodization which can effectively improve strength and power is the phased block model. This model is characterised by several mesocycles, each with a distinct training stimulus (4, 11, 25). The mesocycles are performed in a logical order, whereby the previous block prepares the athlete for subsequent blocks. These mesocycles include hypertrophic, basic strength and maximal strength phases (4, 11, 25). Block periodization is marked by a constant increase in intensity with a decrease in training volume across the mesocycles (3).

Autoregulation is the adjustment of a strength program based on an individual's readiness to train on a daily or weekly basis (8, 12, 13), for instance by the selection of intensity or volume by the athlete based on their perception of the difficulty of the session. Autoregulation as a means of adjusting the variables of training is not a new approach in strength and conditioning (S&C) practice, however, it is a less commonly studied form of periodization, with limited current research (8, 12, 13). As individuals adapt to training stimuli at different rates, it has been proposed that autoregulated (AR) training may result in greater strength gains when compared to a traditional percentage based fixed loading (FL) program (13) as it can account for fluctuations in strength capabilities across a training mesocycle.

Successful application of AR training has been noted in both physiotherapy patients and collegiate athletes (8, 12, 13). For instance, Mann et al. (13) allowed collegiate athletes to self-adjust the weight used in their fourth set based on their third set performance. The outcome of the study showed that the AR programming was more effective in increasing bench press and squat strength over 6 weeks compared to a traditional linear periodised model (13). However, the results from this study must be treated with care, as the volume of training was not equated between the two training programs.

McNamara and Stearne (14) attempted to equate total volume of training between an AR group and a group following a nonlinear periodised training program while manipulating the intensity of training for both groups. The authors found that AR training significantly increased leg press scores in beginner weight trainers compared to non-linear periodization. The AR group was instructed to choose between 3 workouts of varying intensities depending on how motivated, and energetic they felt before each session (10-, 15- or 20- repetitions of various free weight exercises). A limitation of this study design arose in that the AR group had fewer choices of intensity towards the final weeks of the program because of the necessity to equate volume for both programs and therefore the ability to self-adjust was limited by this. Similarly, there is a need for further research to be conducted with experienced resistance trainers to observe if similar gains in strength are elicited.

Colquhoun et al. (7) compared a fixed non-linear periodization model to one which was flexible (AR) in a 9-week program with resistance trained men. Those subjects who were assigned to the AR group were able to select in which order to perform 3 workouts (hypertrophy, strength or power) whereas the order of workouts was stipulated for the other

group. Additionally, subjects were able to adjust the load lifted based on the previous training session. In contrast to traditional methods, whereby loads are determined by percentages of 1RM, here progression throughout the training cycle was dictated by the subject. The outcome of this study showed similar gains in strength between groups, which authors attributed to the same total volume across the intervention.

One challenge in studying AR training is in quantifying the intensity of training and assigning appropriate training loads in order to attain the desired adaptations. Zourdos et al. (26) was the first to investigate the use of an adapted rate of perceived exertion scale (RPE) in order to adjust intensity of training on a set to set basis. After the performance of each set, subjects were asked to estimate how many more repetitions they thought they could perform. The number they reported was then defined this as their repetitions in reserve (RIR). Zourdous et al., found that the use of RPE to gauge RIR was effective in autoregulating resistance intensity during training, whereby the scale allows for practical feedback in order to determine appropriate intensity for the subsequent set/session. The authors noted that the accuracy of the reported RIR was better at higher intensities - at the lower intensities effort due to load was sometimes confused with fatigue. Helms et al. (10) then implemented this RIR scale to determine intensity in comparison to a more traditional measure of intensity (percentage of one repetition maximum - %1RM), in order to account for a subject's readiness to train. The authors noted that the RPE and RIR scales were a useful tool in accurately determining training intensity for the squat instead of relying primarily on a traditional percentage based model. They also noted a strong inverse relationship between %1RM and reported RIR.

There are a number of potential mechanisms which might make an AR approach to training more effective. For instance, AR might improve adherence as the athlete has more perceived control over the program and the enjoyment of training might be greater. Alternatively, AR might allow for the stimulus to be closer to optimal, as the athlete can adjust the loading based upon their readiness to train. Finally, AR might allow the athlete to increase the training load that they use in line with their increasing strength over the course of the program. One problem with research in this area is that it is difficult to elucidate the mechanism of effect due to problems in the research design of the previous research in this area (as highlighted in the review above). The purpose of this study was therefore to test the hypothesis that an AR program would be more effective at increasing strength as it allows the intensity of training to be adjusted in line with the increasing strength level of the athlete across the 12 weeks. The RIR method can be used to specify intensities taking account of these daily changes whereas the traditional approach of prescribing a %1RM does not allow the intensity to be altered. This study therefore compared a FL program stipulated by %1RM intensities versus an AR program described by RIR.

METHODS

Experimental approach to the problem

This study was a randomised clinical trial and was registered on www.researchregistry.com (registration number: researchregistry2046). Subjects were randomly assigned to either a FL or AR training program designed to improve squat strength. The subjects' strength in the front squat (FS) and back squat (BS) was assessed both before and after the training program.

The FL and AR programs were identical apart from the method used to specify intensity. The intensity in the FL program was specified based upon a pre-determined percentage of the pre-test 1RM of the subjects. The intensity of the AR program was instead specified by RIR i.e. how many more repetitions over and above the stipulated number the subject felt able to perform with a given load. The specified RIR was chosen such that the intensity of training was of similar magnitude relative to the subjects' pre-test scores and progressed in a similar way to the FL across the 12-week program.

Subjects

The thirty-one subjects were experienced strength trained males who had engaged in resistance exercise at least twice per week for more than two years. Subject numbers were based on a prospective calculation of the required number of subjects to achieve a power of 0.85 that was performed using Cohen's h based upon a standardized difference of 1.2 and an alpha level of 0.05. This calculation suggested a final subject number of 12 per group (24 in total). However to account for subject drop out, an additional 30% were recruited.

A prerequisite of participation was the ability to execute both FS and BS correctly (10) as per the assessment of the principal investigator who is a UKSCA accredited strength and conditioning coach. The subjects had to be able to squat below parallel with a weighted barbell equivalent to bodyweight or more. Both experimental groups comprised strength and powerlifting-trained athletes, actively training in various sports including soccer, Gaelic football, golf, field hockey, track and field, powerlifting and weightlifting. There were no significant differences ($p > 0.05$) between the groups in terms of the pre-test comparisons of subject characteristics including FS and BS performance (Table 1). All subjects volunteered

for the study after having being informed of the risks and benefits of the study, signed an informed consent form and completed a PAR-Q document. The study was approved by St Mary's University ethics committee.

Table 1. Participant characteristics. No significance difference was found between pre-test characteristics for any variable ($p > 0.05$). Note: 1RM = one repetition maximum.

	Fixed Loading (n = 16)	Autoregulated (n = 15)
Age (years)	28.3 ± 5.6	27.9 ± 5.3
Body Mass (kg)	82.5 ± 8.9	83.2 ± 9.7
Height (cm)	177.8 ± 6.5	179.6 ± 6.5
1RM Front Squat	111.3 ± 19.6	120.7 ± 26.3
1RM Back Squat	129.1 ± 21.3	141.2 ± 29.4

Procedure

The initial testing day was utilised to collect each subject's anthropometric data (age, height, and body mass) and 1RM in BS and FS using the protocol below. The subjects were then randomly assigned using a random number generator function in Microsoft Excel to one of the two training programs to adhere to for a 12-week period. Following completion of the training program, subjects were retested using the same protocols. All testing took place at a privately owned strength and conditioning facility in County Down, Northern Ireland.

Subjects worked independently and were not supervised during the program. Instead, adherence was monitored by a weekly email. In addition, subjects recorded each session, noting the kilograms achieved per set in an Excel spreadsheet. Additional feedback recorded in a logbook included the rate of perceived exertion for the session using Borg's RPE scale (6). The individual Excel spreadsheets were collected at the end of the 12-week program. Subjects were allowed to continue sports specific training outside of the study, which did include resistance training such as, bench press, snatch, clean and jerk. They were instructed not to perform any other squat training throughout the course of the 12-week intervention. No nutritional or hydration advice was given to the subjects prior to, during or after the study.

1RM Testing Protocol

Subjects followed the same warm up for each testing day which included light stretching, foam rolling, and resistance exercises including 2 sets of 10 repetitions each of goblet squats, lunges, and scapular push ups, followed by a 1 minute-rest. The 1RM testing protocol was derived from Baechle and Earle (1). The subject performed a set of 10 repetitions with the empty barbell (20kg) with a 1 minute- rest. A conservative load was then estimated that allowed the subject to perform 3-5 repetitions by adding 10-20% 1RM. A 2 minute rest period was provided. An estimated load was then chosen that allowed completion of 2-3 repetitions followed by 2-3 minutes rest. Further load increases were made (10-20% 1RM) and subjects were instructed to attempt 1 repetition followed by a 2-4 min rest. This was repeated until a 1RM was achieved. If a subject failed with a given load 3 times the preceding load was considered their 1RM (7). FS 1RM was tested first, followed by a recovery period of 10 minutes before the same protocol was performed for BS 1RM. Monitoring of safe and accurate technique was performed by the principal investigator.

Resistance Training Program

The 12-week resistance training program for each group can be seen in Table 2. All subjects exercised 2 days per week with at least 48 hours recovery recommended between sessions, and the exercises performed were the same for each group. The groups differed only in the intensity of training, as described below.

Table 2. A description of the block periodization template (35) used for the 12-week strength program. Fixed loading (FL) were explicitly instructed as to training intensity. The autoregulated group (AR) were given a 'repetitions in reserve' (RIR) guideline to determine intensity.

Programme Variable	Phase 1 (Week 1- 4)	Phase 2 (Week 5-8)	Phase 3 (Week 9-12)
FL: Training Intensity (%)	65, 67.5, 70, 72.5	77.5, 80 82.5, 87.5	87.5, 90, 92.5, 95
AR: RIR	4, 3, 2, 1	4, 3, 2, 1	2, 1, 0, MAX
Training volume (repetitions)	3 x 10	4 x 5	3 x 3
Rest Time	2-3 mins	2-3 mins	2-3 mins
Day 1	Front Squat		
Day 2	Back Squat		

Subjects recorded all their results, in kilograms, for each session for FS and BS. Additional feedback was recorded on how they felt in a logbook to monitor adherence to the program. The subjects were also required to record their RPE for each set.

The program consisted of three mesocycles, each of 4 weeks in duration, with decreasing training volume and increasing intensity. Each mesocycle progressed from hypertrophy to basic strength to a maximal strength phase. The FL group received explicit instruction regarding the volume and intensity of each session (Table 2). The AR group completed a program with the same volume as the FL group (i.e. with the same number of sets and repetitions prescribed for each session). However, the intensity was autoregulated as follows. The subject was required to choose a load that related to the feeling of having a required number of RIR. The RIR number for each week was chosen such that the intensity was theoretically the same as for the FL group (based on the pre-test strength levels of the subjects). This was done using Table 3 which provides an estimate between the percentage of 1RM and the maximum number of repetitions that can be performed with that load and that was based on previous research (1, 10, 18). Thus the subject chose a load (kg) to perform the necessary repetitions (10, 5 or 3) with a further 4, 3, 2 or 1 RIR. For example, if the prescription was to have a subjective feeling of having "4 RIR" then the athlete chose a load that they could perform a further 4 repetitions if required to.

Table 3. The relationship between submaximal loads (% one repetition maximum; 1RM) and the number of repetitions that can be performed at that load The AR repetitions in reserved (RIR) were formulated from this table. This table has been adapted from Baechle and Earle (1). Note: FL = fixed loading; AR = autoregulated.

Percentage 1RM	Maximum Repetitions at that Load	Number of Repetitions per Set for FL Programme	AR RIR Instruction
100	1		MAX
95	2	3	0
92.5	3	3	-1
90	4	3	-2
87.5	5	3	-3
85	6	5	-1
82.5	7	5	-2
80	8	5	-3
77.5	9	5	-4
72.5	11	10	-1
70	12	10	-2
67.5	13	10	-3
65	14	10	-4

Statistical Analysis

All statistical testing was performed in IBM SPSS Statistics (Version 24; IBM Corporation, 1 Armonk Road, NY, USA). Two way repeated measures analysis of variance (ANOVA) with time (pre- and post-test) as the within subjects factor and training group (AR or FL) as the between subjects factor was used to test for differences in the FS and BS performances and body mass (2 time points). Repeated measures factorial ANOVA was also used to test for differences in training intensity, RPE and training volume (12 time points). The Greenhouse-

Geisser correction was used in cases where the sphericity assumption was violated. Alpha was set as $p < 0.05$ a priori and partial eta squared η_p^2 was reported as a measure of effect size for the ANOVAs. In addition, Cohen's *d* was calculated to give the standardized difference between pre- and post-test scores for each group and squat condition. Finally Pearson's correlation coefficient *r* was calculated to assess the magnitude of the relationship between training intensity and RPE scores.

RESULTS

All subjects reported that they were adherent to the program in response to the weekly emails. Unfortunately, two members of the FL group did not complete the training log books and this was only discovered at the end of the intervention. Analysis of the completed training log books indicated that the FL group completed 99.1% of the programmed sessions and the AR group completed 98.6%. The analysis of FS and BS pre- and post-test scores was completed both including and excluding the two subjects from the FL group who did not complete the log book. The results were not materially different when the two subjects from the FL group were excluded and so the results from the complete data set are presented here.

The body mass of the subjects increased over the 12-week program ($p = 0.006$, $\eta_p^2 = 0.236$) but there was no difference between groups. Both groups showed a significant increase in FS and BS performance (Table 4), but the magnitude of this was significantly greater for the AR program (time × group interactions: FS $p = 0.004$, $\eta_p^2 = 0.255$; BS $p = 0.006$, $\eta_p^2 = 0.233$).

Table 4. Pre- and post-test squat scores. * = post-test score is significantly greater than pre-test score ($p < 0.05$). † = increase in squat score for autoregulated is significantly greater than fixed loading ($p < 0.05$).

	Pre-Test	Post-Test	Standardised Difference
Front Squat			
Fixed Loading	111.3 ± 19.6 (99.5 – 123.1)	120.6 ± 18.3* (109.1 – 132.0)	+0.48
Autoregulated	120.7 ± 26.3 (108.5 – 132.9)	134.8 ± 26.1* (123.0 – 146.6)	+0.53†
Back Squat			
Fixed Loading	129.1 ± 21.3 (116.0 – 142.1)	138.2 ± 19.5* (125.4 – 151.0)	+0.44
Autoregulated	141.2 ± 29.4 (127.7 – 154.7)	156.4 ± 29.8* (143.3 – 169.7)	+0.51†

Figure 1 shows the weekly average FS and BS training intensity (%1RM) for AR and FL groups. The training intensity for the AR group was significantly greater than the FL group (time × group interactions: FS $p < 0.001$, $\eta_p^2 = 0.240$; BS $p = 0.006$, $\eta_p^2 = 0.159$). Table 5 presents a comparison of the intensities employed in the first and final weeks of training. There was no difference in intensity between the two groups in Week 1, however in Week 12 the AR group used a significantly greater intensity even when accounting for the fact that they had made greater gains in strength (time × group interactions: FS $p = 0.002$, $\eta_p^2 = 0.289$; BS $p = 0.007$, $\eta_p^2 = 0.236$). Figure 2 shows the average RPE feedback for FS and BS sessions across the 12 weeks of FL and AR training programs. The RPE of the AR group was significantly greater than the FL group for the BS but not the FS (time × group interactions: FS $p = 0.056$, $\eta_p^2 = 0.088$; BS $p < 0.001$, $\eta_p^2 = 0.171$). There was a moderate

positive correlation between training intensity and RPE for the AR group (FS r = 0.61, BS r = 0.67) and a strong positive correlation for the FL group (FS r = 0.71, BS r = 0.80). Finally, there was no significant difference in the average weekly volume load used by the two groups (Figure 3; group effect: p = 0.088, η_p^2 = 0.177).

Figure 1. Average training intensity (% of one repetition maximum) for front (FS) and back (BS) squat. The training intensity for the autoregulated (AR) group was significantly greater than the fixed loading (FL) group (time × group interactions: FS p < 0.001, η_p^2 = 0.240; BS p = 0.006, η_p^2 = 0.159). Note that the training intensity for the FL group was the same for FS and BS each week thus only one line for FL is displayed.

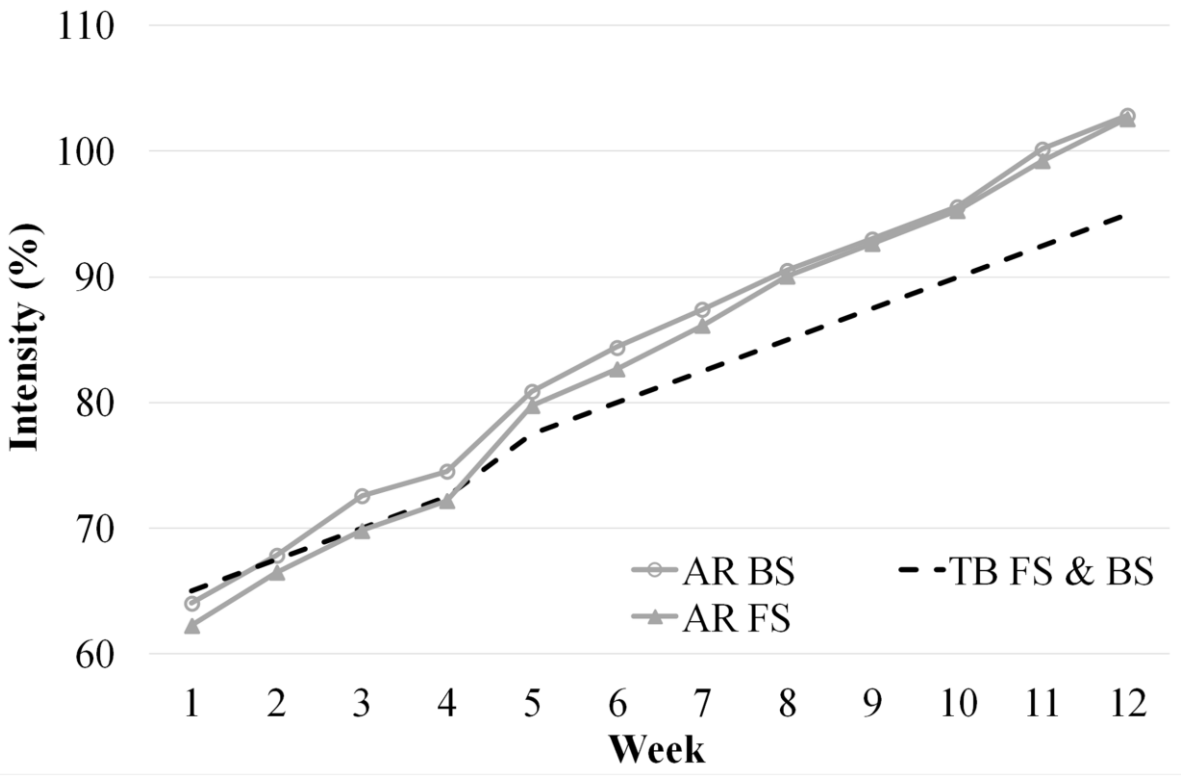

Figure 2. Average RPE rating for each of the training sessions for front (FS) and back (BS) squat. A group average was calculated from the subjects' reported session RPE using Borg's RPE scale (6). The RPE of the autoregulated (AR) group was significantly greater than the fixed loading (FL) group for the BS but not the FS (time × group interactions: FS $p = 0.056$, $\eta_p^2 = 0.088$; BS $p < 0.001$, $\eta_p^2 = 0.171$).

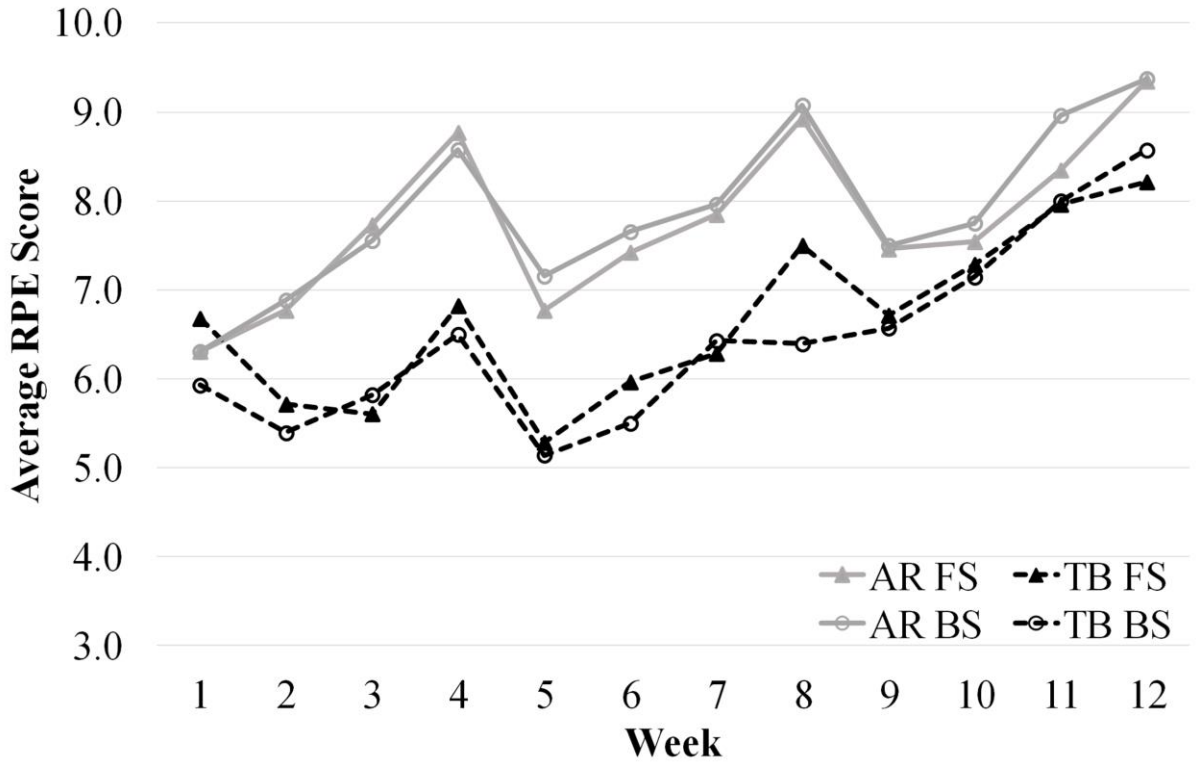

Figure 3. Average total weekly volume load. There was no significant difference between the autoregulated (AR) and fixed loading (FL) groups (group effect: $p = 0.088$, $\eta_p^2 = 0.177$).

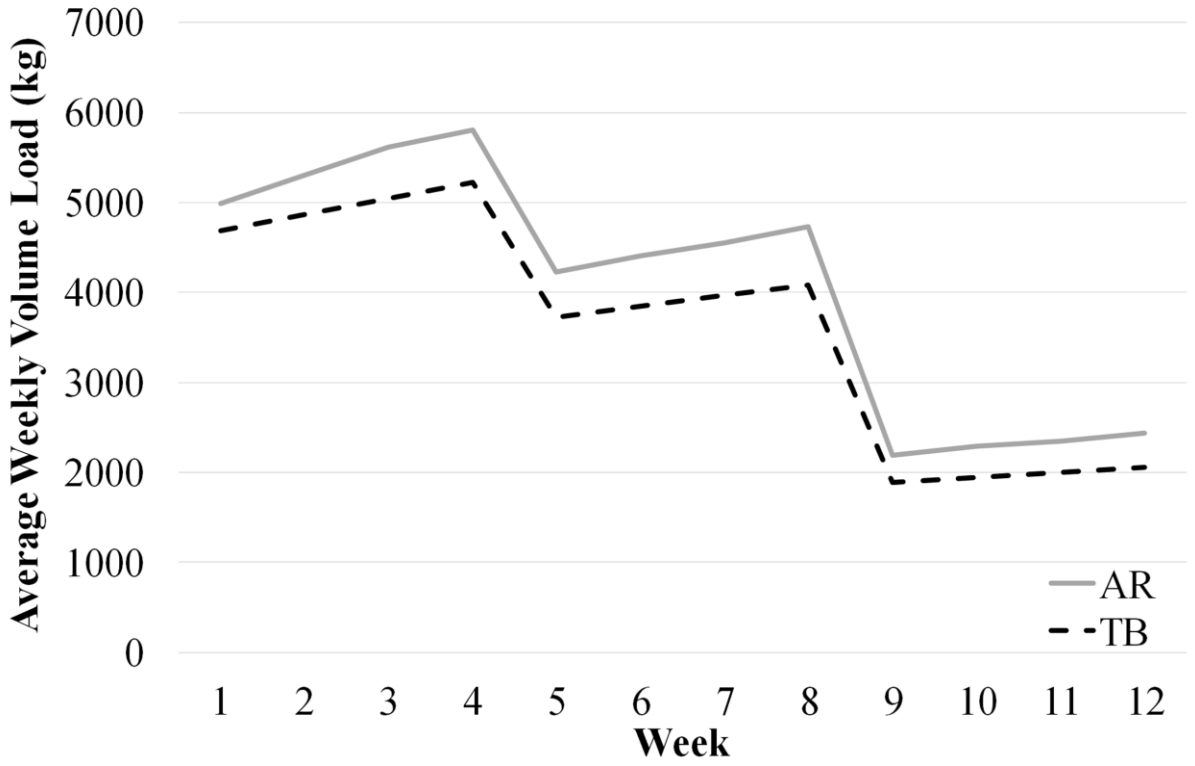

Table 5. Average training intensity relative to pre- and post-test 1RM. Week 1 as a percentage of pre-test 1RM and Week 12 as a percentage of post-test 1RM (* = significantly different to fixed loading; $p < 0.05$). Note: 1RM = one repetition maximum.

	Week 1 (as % Pre-Test 1RM)	Week 12 (as % Post-Test 1RM)
Front Squat		
Fixed Loading	65.0 ± 0.0	87.4 ± 3.4
Autoregulated	62.2 ± 8.1	91.3 ± 4.1*
Back Squat		
Fixed Loading	65.0 ± 0.0	88.5 ± 4.1
Autoregulated	64.0 ± 6.5	93.0 ± 6.2*

DISCUSSION

The results of this study indicate that both the AR and FL groups showed a significant enhancement in 1RM FS and BS performance, however the magnitude of the gain for the AR group was greater than the FL group (FS: η^2 =0.255 and BS: η^2 =0.233). This finding means that the null can be rejected and lends support to the contention that autoregulation by "repetitions in reserve" can lead to greater improvements in strength over a 12-week training program than a fixed loading scheme. In addition, in this study the AR group trained at a higher intensity as the AR protocol allowed the subjects to increase the load lifted in line with their increasing strength levels. The greater intensity of training seems a likely explanation for the greater strength gains.

A consideration of Figure 1 shows that the AR group trained at a significantly greater intensity in both the FS and the BS over the course of the study. As was hypothesized, as the strength levels of the AR group increased, the autoregulated nature of the program permitted the subjects to increase the load lifted beyond that of a fixed percentage based prescription. Although the intensities that were prescribed to the group were theoretically the same when considered relative to the pre-test 1RM, the AR group were able to adjust the load they lifted such that the intensity at which they performed the exercise was actually relative to their strength levels on the day. In fact, as shown in Table 5, the AR group were actually training at a higher percentage even when accounting for the fact that they had made greater strength gains than the FL group. It seems plausible to suggest that the main reason for the greater strength improvements of the AR group was therefore due to the greater intensity at which they trained. This is supported by the fact that the total number of lifts was the same for the two groups. Figure 3 does show a non-significant trend (p = 0.088) towards the AR group

352 training with greater volume load. However, this difference is purely driven by the fact that
353 the AR group trained at a higher intensity and had higher pre-test 1RM scores.

354

355 Figure 2 indicates that on average the AR group displayed higher RPEs for the duration of
356 this study – although the difference was only significant for the BS, it was also probable for
357 FS (p = 0.056). This provides further support for the contention that the AR group were
358 training at a higher intensity than the FL group. It is also interesting to compare the pattern in
359 RPEs between the AR and FL groups over the course of the study, bearing in mind the nature
360 of the program. In particular, this program consisted of three, four week blocks each of
361 which was designed to start relatively easy in the first week, and then increase in difficulty
362 over the course of the block. This pattern is clearly evident in the mean RPEs of the AR
363 group. In contrast, it is much harder to identify three clear cycles in the pattern of RPEs for
364 the FL group. This finding seems to suggest that the AR program was more successful in
365 allowing the subjects to train at the desired relative intensity. In contrast, because the FL
366 group were not able to adjust the load they were training with based upon their readiness to
367 train, it meant that in some instances they may have had to train with an intensity that was
368 greater or smaller than desired.

369

370 A notable potential limitation of this study was the difficulty in matching the intensities of the
371 FL and AR programs. This was achieved by reference to Table 3 which illustrates a
372 theoretical relationship between the load lifted (as a percentage of 1RM) and the maximum
373 number of repetitions that can be performed with that load. However, this relationship is
374 highly variable and depends on the characteristics of the individual in question (18).
375 Similarly, the matching of intensities also depended on how accurately subjects in the AR

group were able to determine the correct load for a given RIR. Zourdos et al. (26) have suggested that more experienced lifters are better at gauging the number of RIR and become more accurate when loads are near maximal, and RPE is higher. Similarly, Helms et al. (10) suggested that subjects are able to more accurately determine what intensity to work at when the RIR were at a lower number (e.g. 1-4 RIR). A consideration of Table 5 does allow the intensities chosen by the AR group to be evaluated (relative to the intended intensity). For instance, in Week 1 the AR group trained at 62.2% and 64.0% of their pre-test 1RM in the FS and BS respectively, whereas the target intensity was 65.0%. In Week 12, the AR group trained at 91.3% and 93.0% of their post-test 1RM, when the target intensity was 95% of their current 1RM. These results do provide some comfort that the intensities chosen by the AR group were broadly as programmed, although they may have been a little low.

In conclusion, this study demonstrated that prescribing intensities based upon RIR allowed the subjects to adjust the load they used to accommodate increases in strength during the course of the program thus allowing them to train at a higher intensity. This in turn led to greater improvements in strength over the course of a 12-week training program.

PRACTICAL APPLICATIONS

The RIR method proposed in this study would be suitable to use with experienced weight trainers who have previously completed a resistance training program. The successful application of the RIR method requires the ability to determine and adjust to subjective feedback and ultimately use this information to adjust the intensity of training on a set by set basis within the parameters of RIR. It is recommended that the RIR method is used for

compound exercises such as squat or bench. Other resistance exercises such as weightlifting derivatives require further research. The RIR method lead to greater incremental loading, meaning higher training intensities were realized sooner in the duration of the program. If the aim of a mesocycle is to realise maximal strength gains in a minimal time frame, the RIR method may prove advantageous.

References:

1. Baechle, TR, Earle, RW. *Essentials of Strength and Conditioning (3rd Edition)*. Champaign, IL: Human Kinetics, 2008.
2. Baker, D, Wilson, G, Carlyon, R. Periodization: The effect on strength of manipulating volume and intensity. *J Strength Cond Res 8*: 235-242, 1994.
3. .Bartolomei, S, Hoffman, JR, Merni, F, Stout, JR. A comparison of traditional and block periodized strength training programs in trained athletes. *J Strength Cond Res* 28: 990-997, 2014.
4. Bompa, TO, Haff, GG. *Periodization: Theory and Methodology of Training*. Champaign, IL: Human Kinetics, 2009.
5. Bondarchuk, AP. *Transfer of Training in Sports*. Muskegon,MI: Ultimate Athlete Concepts, 2007.
6. Borg, G. *Borg's Perceived Exertion and Pain Scales*. Champaign IL: Human Kinetics, 1998.
7. Buford, TW, Rossi, SJ, Smith, DB, Warren, AJ. A comparison of periodization models during nine weeks with equated volume and intensity for strength. *J Strength Cond Res 21*: 1245-1250, 2007.
8. Colquhoun, RJ, Gai, CM, Walters, J, Brannon, AR, Kilpatrick, MW, D'Agostino, DP, et al. Comparison of powerlifting performance in trained men using traditional and flexible daily undulating periodization. *J Strength Cond Res 31*: 283-291, 2017.
9. DeLorme, TL, West, FE, Shriber, WJ. Influence of progressive-resistance exercises on knee function following femoral fractures. *J Bone Joint Surg Am* 32: 910-924, 1950.

436 10. Haff, GG, Triplett, NT. *Essentials of Strength Training and Conditioning (4th*
437 *Edition)*. Champaign, IL: Human Kinetics, 2015.

438 11. Helms, ER, Cronin, J, Storey, A, Zourdos, MC. Application of the repetitions in
439 reserve-based rating of perceived exertion scale for resistance training. *Strength Cond*
440 *J* 38: 42-49, 2016.

441 12. Issurin, V. Block Periodization Versus Traditional Training Theory: A Review. *J*
442 *Sports Med Phys Fitness* 48: 65-75, 2008.

443 13. Knight, KL. Knee rehabilitation by the daily adjustable progressive resistive exercise
444 technique. *Am J Sports Med* 7: 336-337, 1979.

445 14. Mann, JB, Thyfault, JP, Ivey, PA, Sayers, SP. The effect of autoregulatory
446 progressive resistance exercise vs. linear periodization on strength improvement in
447 college athletes. *J Strength Cond Res* 24: 1718-1723, 2010.

448 15. McNamara, JM, Stearne, DJ. Flexible nonlinear periodization in a beginner college
449 weight training class. *J Strength Cond Res* 24: 17-22, 2010.

450 16. Miranda, F, Simão, R, Rhea, M, Bunker, D, Prestes, J, Leite, RD, et al. Effects of
451 linear vs. daily undulatory periodized resistance training on maximal and submaximal
452 strength gains. *J Strength Cond Res 25*: 1824-1830, 2011.

453 17. Rhea, MR, Alderman, BL. A meta-analysis of periodized versus non periodized
454 strength and power training programs. *Res Q Exerc Sport* 75: 413-422, 2004.

455 18. Richens, B, Cleather, DJ. The relationship between the number of repetitions
456 performed at given intensities is different in endurance and strength trained athletes.
457 *Biol Sport* 31: 157-161, 2014.

458 19. Shimano, T, Kraemer, WJ, Spiering, BA, Volek, JS, Hatfield, DL, Silvestre, R, et al.
459 Relationship between the number of repetitions and selected percentages of one

repetition maximum in free weight exercises in trained and untrained men. *J Strength Cond Res* 20: 819-823, 2006.

20. Siff, MC, Verkhoshansky, YV. *Supertraining (4th Edition)*. Denver, CO: Supertraining International, 1999.
21. Stone, MH, Chandler, TJ, Conley, MS, Kramer, JB, Stone, ME. Training to muscular failure: Is it necessary? *Strength Cond J* 18: 44-48, 1996.
22. Stone, MH, Potteiger, JA, Pierce, KC, Proulx, CM, O'Bryant, HS, Johnson, RL, et al. Comparison of the effects of three different weight-training programs on the one repetition maximum squat. *J Strength Cond Res 14*: 332-337, 2000.
23. Storen, O, Helgerud, J, Stoa, EM, Hoff, J. Maximal strength training improves running economy in distance runners. *Med Sci Sports Exerc* 40: 1089-1094, 2008.
24. Sunde, A, Støren, Ø, Bjerkaas, M, Larsen, MH, Hoff, J, Helgerud, J. Maximal strength training improves cycling economy in competitive cyclists. *J Strength Cond Res 24*: 2157-2165, 2010.
25. Verkhoshansky, Y. Speed-strength preparation and development of strength endurance of athletes in various specializations. *Sov Sports Rev* 21: 120-124, 1986.
26. Wisløff, U, Castagna, C, Helgerud, J, Jones, R, Hoff, J. Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *Br J Sports Med* 38: 285-288, 2004.
27. Zourdos, MC, Klemp, A, Dolan, C, Quiles, JM, Schau, KA, Jo, E, et al. Novel resistance training–specific rating of perceived exertion scale measuring repetitions in reserve. *J Strength Cond Res* 30: 267-275, 2016.