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Research article

DYNAMIC TRAINING VOLUME: A CONSTRUCT OF BOTH TIME UNDER TENSION AND VOLUME LOAD

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ABSTRACT

The purpose of this study was to investigate the effects of three different weight training protocols, that varied in the way training volume was measured, on acute muscular fatigue. Ten resistance-trained males performed all three protocols which involved dynamic constant resistance exercise of the elbow flexors. Protocol A provided a standard for the time the muscle group was under tension (TUT) and volume load (VL), expressed as the product of the total number of repetitions and the load that was lifted. Protocol B involved 40% of the TUT but the same VL compared to protocol A; protocol C was equated with protocol A for TUT but only involved 50% of the VL. Fatigue was assessed by changes in maximum voluntary isometric force and integrated electromyography (iEMG) between the pre- and post-training protocols. The results of the study showed that, when equated for VL, greater TUT produced greater overall muscular fatigue ($p \leq 0.001$) as reflected by the reduction in the force generating capability of the muscle. When the protocols were equated for TUT, greater VL ($p \leq 0.01$) resulted in greater overall muscular fatigue. All three protocols resulted in significant decreases in iEMG ($p \leq 0.05$) but they were not significantly different from each other. It was concluded that, because of the importance of training volume to neuromuscular adaptation, the training volume needs to be clearly described when designing resistance training programs.

KEY WORDS: Resistance training, maximal voluntary contraction, fatigue, electromyography.

INTRODUCTION

Training volume has been recognized as an important variable in resistance training (Benedict, 1999). However, there is a lack of consensus in regard to the optimal volume needed for strength or hypertrophic enhancements which in part may be due an absence of a universally accepted definition of training volume.

Volume is most commonly calculated as the product of the load and the number of repetitions and expressed as volume load (VL). The calculation is an approximation of mechanical work (force × distance) with the assumption that all the repetitions are performed through the same range of motion (Stone et al., 1999). Volume load may be considered a superior method of calculating volume compared to purely counting total repetitions because it recognizes that the load is a contributing factor to volume. However, this method does not differentiate between the load and repetitions because similar VLs may be obtained from lifting different loads.

Training volume can also be calculated as the cumulative time that a muscle group is under tension or contraction during a training session, referred to as time under tension (TUT). However, little is known about the effect of TUT as a training parameter. Positive (Wescott et al., 2001) and negative (Keeler et al., 2001; Munn et al., 2005) associations with increased TUT and strength enhancements have been reported. A criticism of these studies is the lack of standardization for training load by either using different training loads or by prescribing load within a range (i.e. 6-8RM). As a result, interpreting the effects of TUT when confounded by training load is difficult.

Only one study has specifically compared the effects of TUT and VL and controlled for training load (Tran et al., 2006). Insight into training protocols may be initially gained by monitoring the acute muscle fatigue because of its association with strength enhancement (Rooney et al., 1994; Schott et al., 1995). Tran et al. (2006) found that manipulating either TUT or VL significantly influenced muscle contractile twitch characteristics, which is considered to reflect impairments in force production at or distal to the neuromuscular junction (peripheral fatigue). However, the overall muscle fatigue response, defined as a temporary exercised-induced reduction in force generating capabilities (Gandevia, 2001), was only significant for differences in TUT. They concluded that, when training load is equated, the major determinant of muscle fatigue is TUT, and attributable to fatigue mechanisms in the muscle contractile components. However, Tran et al. (2006) assessed central and overall muscle fatigue responses at 1 min post-completion of the fatiguing protocol due to the time it took to assess muscle twitch characteristics. It is possible that greater central and overall muscle fatigue responses were elicited, but due to the recovery that may have occurred in the 1 min it took to perform the muscle twitch assessment, it was not detected.

Therefore, the purpose of this study was to evaluate the immediate effects of manipulating TUT and VL on central and overall muscle fatigue responses following a bout of single-arm elbow flexions.

METHODS

Participants

Ten university-aged males participated in the study (age = 25.8 ± 3.15 yrs; mass = 86.5 ± 15.2 kg). All participants were strength-trained with a minimum of one year of upper body resistance training. Written consent was obtained prior to participation and all participants were briefed on the purpose of the study and potential risks from participating in the study. Approval for the study was granted by the University Human Research Ethics Committee.

Experimental design

Participants performed each fatigue protocol, in random order, on separate days with approximately 48-72 hrs between testing sessions. Ninety percent of the 10RM load was used as the load for all fatiguing protocols to ensure the VL was consistent and could be maintained within and between trials (Benson et al., 2006). All participants were able to complete the prescribed repetitions.

Prior to participation in the testing session, each participant completed two familiarization sessions, separated by 48-72 hrs. All sessions were supervised by the principal investigator and participants were asked to refrain from performing any resistance training targeting the forearm flexors for the duration of the study.

Fatigue protocols

The three different training protocols were designed to manipulate either concentric TUT or VL (Table 1). Participants were instructed to keep time with a metronome set at the specific cadence for the protocol. In protocol B, participants performed the same VL as in protocol A but with only 40% of the concentric TUT. In protocol C, participants performed 50% of the VL compared to protocol A but with equal TUT. Manipulation of the concentric phase was chosen to be consistent with other dynamic training TUT studies (Keeler et al., 2001; Wescott et al., 2001) and because increased concentric contractions have been associated with greater increases in muscle fibre cross sectional area (Gillies et al., 2006).

Familiarization sessions

Following an initial rest period (5 min) participants performed a warm-up consisting of three sets of 10

Table 1. Repetition scheme for three fatiguing protocols (CON = concentric, ECC = eccentric).

Protocol	Sets	Repetitions	CON Phase (s)	ECC Phase (s)	Volume load *	Total CON TUT (s)	Total ECC TUT(s)
A	3	10	5	2	27	150	60
B	3	10	2	2	27	60	60
C	3	5	10	4	13.5	150	60

Note: Asterisks (*) denotes volume load was calculated by multiplying number of repetitions by ninety percent (of 10RM). Example calculation of volume load for protocol A = 3 × 10 × 0.9 = 27.

repetitions of dynamic constant external resistance (DCER) elbow flexion. Three minute rest periods were provided between sets with a load of 50% of the estimated 10RM. All warm-ups during the familiarization sessions were performed using the training regimen of protocol A to familiarize subjects with the repetition cadence prior to the 10RM test.

Testing for the 10RM load was performed using the repetition scheme of protocol A because this protocol involved both the high TUT and high VL parameters (Table 1). Participants performed single-arm standing dumbbell curls of the dominant arm with their backs to the wall to maintain form. One complete repetition consisted of moving the arm through the full range of elbow motion. The participants were instructed to maintain a supinated grip, avoid any extraneous body movement, and keep time with a pre-set metronome throughout the test. Participants started at an initial load of 75% of the estimated 1RM. The load was adjusted accordingly by 100g – 2kg increments until 10RM was identified. Five minute rest periods between 10RM attempts were provided to minimize fatigue. No participants required more than 3 attempts to identify the 10RM.

Following the 10RM test, the remaining protocols in random order were performed at 50% of the 10RM. This was necessary in order to familiarize the participants with the different contraction cadences required for each protocol. Five minute rest periods were provided between fatiguing protocols.

Testing sessions

Following an initial rest period of 5 min, the participants performed an identical warm-up as in the familiarization session, but utilized the repetition scheme of the fatigue protocol being tested in order to provide participants with additional practice with the timing of lifts. Maximal voluntary isometric contraction (MVIC) and integrated electromyography (iEMG) were measured before and immediately after each fatiguing protocol (Figure 1).

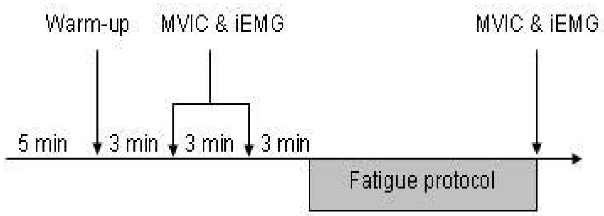

Figure 1. Timeline for an individual testing session.

Set up on the modified preacher curl

Maximal isometric contractions were performed on the modified preacher curl apparatus. The apparatus was adjusted so that the legs and thighs of the participant were at a 90° knee angle to each other and with the chest flush against the arm rest pad (Figure 2). The forearm was fully supinated and rested on an arm pad at a joint angle of 90°. The joint angles were measured with a goniometer. To minimize extraneous body movement, metal clamps were lowered until they pressed firmly against the upper arm. The height of each clamp was measured and recorded for each individual. The wrist of the participants was inserted into a wrist strap attached to the strain gauge. Once the subject was positioned appropriately a standard force of 10N (resting tension) was set to eliminate slack in the wire connecting the strain gauge to the wrist straps.

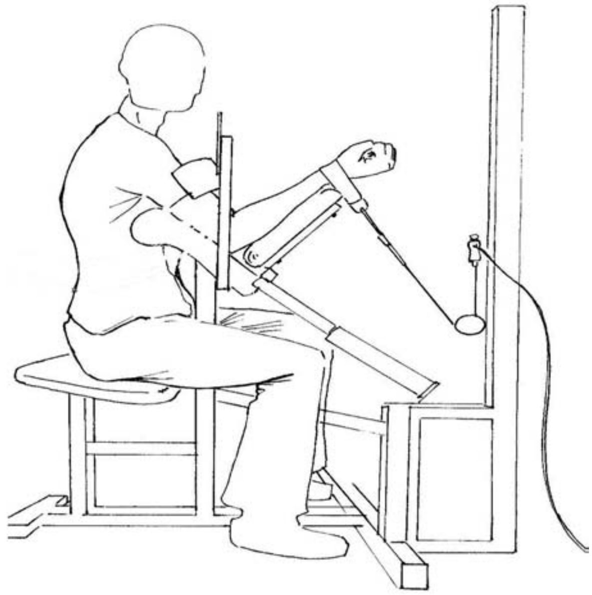

Figure 2. Side profile of the body position on the modified preacher curl apparatus.

Maximal voluntary isometric contraction

Participants performed 2 MVICs before doing the training protocol separated by 3 min rest periods, and one MVIC immediately after the protocol (Figure 1). All MVIC attempts were 3s in duration. The average of the peak pre-protocol MVIC forces was recorded and used for data analysis.

Electromyography

Prior to the electrode placement for the electromyography (EMG), the skin was thoroughly prepared via sanding of the designated area and cleansed with isopropyl alcohol. Electrode placements were marked by non-permanent ink and participants were instructed to redraw the marks when they appeared to fade. A ground electrode was placed on the lateral aspect of the deltoid (Behm et al., 2002). Two surface electrodes (silver-silver chloride, 10 mm in diameter) were placed over the motor point (midbelly) of the biceps brachii and 2 cm superior (proximal one third of the biceps brachii).

EMG data were sampled at 2000Hz and analyzed at 2s of the MVIC for a period of 500ms. Raw EMG was amplified (Biopac Systems Inc. EMG 100 and analog to digital converter, MP100 set at 2000 gain) and filtered (10 – 500Hz). The EMG signal was then rectified and integrated for data analysis using Acknowledge 3.7 software (Biopac Systems, Inc.).

Statistics

Data were analyzed using SPSS 11.5. A two-way analysis of variance (ANOVA) with repeated measures was conducted (3 × 2). The two ANOVA levels included the fatigue protocols (A, B, & C) and the differences between pre- and post-test measures. F ratios that reached $p \leq 0.05$ were considered significant. Student's paired t-tests were performed where significant main effects were detected.

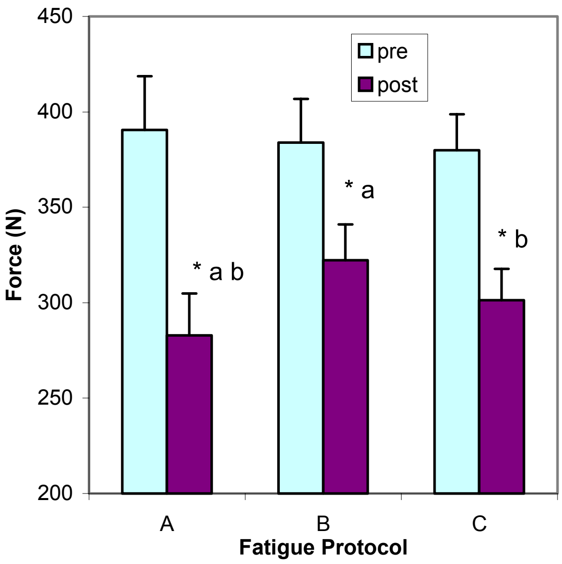

Figure 3. Maximal voluntary isometric contraction measured pre- and immediately post-completion of each fatiguing protocol. Vertical lines represent standard error of the means. Asterisk (*) denotes significant difference from pre- to post-values ($p \leq 0.0005$). Letters a and b denote significant differences from each other ($p \leq 0.01$).

RESULTS

Protocol A, which involved 2½ times more concentric TUT, resulted in a significantly greater ($p < 0.01$) percent decrease in force production (27.62 ± 1.66%) compared to protocol B (15.86 ± 1.35 %). Similarly, the greater VL of protocol A, resulted in significantly greater deficits in force production compared to protocol C (20.25 ± 3.12%). The decreased force production between protocol B and C was not significantly different (Figure 3).

Protocols A, B, and C all resulted in significant ($p \leq 0.05$) decreases in iEMG activity from pre- to post-values (30.28 ± 7.97%, 20.94 ± 6.78 & 21.72 ± 8.17%, respectively). However, no significant differences occurred between the three protocols ($F = 0.46$) (Figure 4).

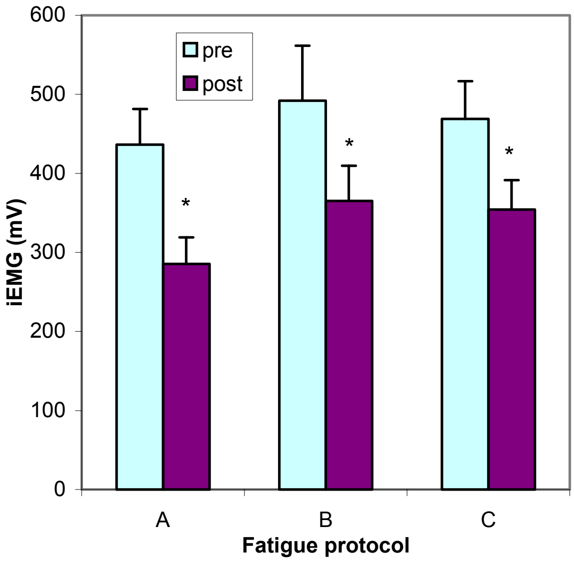

Figure 4. Muscle iEMG activity measured, during E2, pre and immediately post completion of each fatiguing protocol. Vertical lines represent standard error of the means. Asterisk (*) denotes significant difference from pre- to post-values ($p \leq 0.05$).

DISCUSSION

Muscle fatigue

The major findings of this study were that, when VL was equated, greater TUT produced greater overall muscular fatigue as reflected by the reduction in the force generating capability of the muscle. When TUT was equated, greater VL resulted in greater overall muscular fatigue (Figure 3). These results demonstrate that, when training load is equated, DCER exercised-induced fatigue is a product of both TUT and VL. Therefore, a potential discrepancy in training volume may be present with training parameters that fail to control for either VL or TUT.

The results support the findings of Tran et al. (2006) who also found that peripheral muscular fatigue, as reflected by significant changes in muscle twitch properties, increased as a consequence of greater TUT or VL. Impairments to excitation-contraction (E-C) coupling processes have been proposed to account for up to 75% of peak twitch force impairments (Ingalls et al., 1998). The findings from the above study suggest that the majority of overall muscle fatigue observed in the present study may be due to peripheral fatigue mechanisms, largely attributed to impairments in E-C coupling.

Tran et al. (2006) also observed increased TUT resulted in greater impairments in peak twitch force compared to a protocol that had less TUT but more VL, which would suggest that TUT is a greater contributor to peripheral fatigue than VL. This finding was not supported in the present study in regard to overall muscular fatigue (Figure 3) which would imply that impairments in muscle twitch contractile properties are not the only contributing factors to fatigue. However, the present study did not assess peripheral measures of fatigue and can only speculate on the probable causes of the decrease in force generation following the three different protocols.

Potential peripheral muscle fatigue mechanisms may include accumulation of muscle lactate but more recent information is suggesting that lactate is not a major contributor in the development of fatigue (Allen, 2004). Altered ion exchange appears to play a key role in the development of muscle fatigue, particularly calcium (Ca^{++}) kinetics and ions that influence it such as sodium, potassium, and inorganic phosphates. In addition, repeated contractions may result in muscle damage of the sacroplasmic reticulum and t-tubules which would reduce the force generating capabilities of muscle (for review, see Allen (2004)). Ionic mechanisms of fatigue or muscle damage and its relation to TUT and VL require further investigation.

Motor unit activation

Electromyography represents the electrical properties of the muscle and is often used to monitor central drive because of the relationship between the amplitude of the surface EMG and the net motor unit activity (Farina et al., 2004). All fatiguing protocols resulted in significant decreases in iEMG but were not significantly different from each other (Figure 4). The results of the iEMG data suggest that some central fatigue, defined as a temporary decline in voluntary muscle activation (Gandevia, 2001), did occur but was not specific to any protocol. Therefore, central fatigue does not appear to be influenced by manipulating TUT or VL.

The reductions in iEMG are contradictory to the nonsignificant results of muscle activation found by Tran et al. (2006). The discrepancy in the results may be attributable to the different methods used to reflect central fatigue. The authors used an interpolated twitch (IT) during a MVIC, which is considered to be one of the most direct measures of central drive (Gandevia, 2001) compared to iEMG in the present study. However the discrepancy may also be due other factors. Full muscle activation, as evidenced from the IT (Tran et al., 2006), was maintained which suggests that iEMG may be influenced by other factors. Farina et al. (2004) have acknowledged that surface EMG may reflect both central and peripheral mechanisms of fatigue. The reduced iEMG observed in the present study may be attributed to various peripheral factors such as preferential recruitment of type I fibres with low tension potential due to fatigue of type II muscle fibres (Gabriel et al., 2001) or altered electrical conductivity around the muscle fibres due to failure of excitation (Dimitrova and Dimitrov, 2003). It is also possible that 1 min of rest that occurred as a result of the method used to assess motor unit activation and twitch characteristics by Tran et al. (2006) was sufficient to allow some recovery from central fatigue.

The reduction of iEMG immediately following the training protocols in the present study would suggest development of central fatigue, which may account for up to 25% of deficits in force production (Taylor et al., 2006). However, equivocal findings have been reported with regard to the extent and recovery of central fatigue and dynamic exercises. Tran et al. (2006) and Gandevia et al. (1998) found no significant muscle inactivation following a bout of dynamic elbow flexion exercises, whereas Behm et al. (2002) found significant impairments of central drive to last longer than three minutes. A recent study using muscle nerve and motor cortex stimulation have demonstrated that central fatigue of the elbow flexors can recover within minutes following and isometric fatiguing protocol (Søgaard et al., 2006). However, recovery of central fatigue following DCER exercises require further investigation.

CONCLUSION

The present study has shown that muscular fatigue, as reflected by a decrease in the force generation capability of a muscle group, is influenced by the time the muscle group is placed under tension (TUT) and the VL, as measured by the number of repetitions and the load that is being lifted. Training volume has been associated with chronic neuromuscular adaptations and is an important training variable. When prescribing training programs this study suggests that the way in which training volume is calculated may have a significant impact on the neuromuscular changes that occur. People who design programs need to be specific in the way they describe training volume.

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KEY POINTS

- Increase in either time under tension (TUT) or volume load (VL) increases the acute fatigue response, despite being equated for volume (by another method).
- A potential discrepancy in training volume may be present with training parameters that fail to control for either TUT or VL.
- Neural fatigue may be a contributing factor to the development of muscular fatigue but is not influenced by various methods of calculating volume such as TUT or VL.

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