Journal of Athletic Training 2012;47(2):125–129

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original research

A Methodologic Approach for Normalizing Angular Work and Velocity During Isotonic and Isokinetic Eccentric Training

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Context: Resistance exercise training commonly is performed against a constant external load (isotonic) or at a constant velocity (isokinetic). Researchers comparing the effectiveness of isotonic and isokinetic resistance-training protocols need to equalize the mechanical stimulus (work and velocity) applied.

Objective: To examine whether the standardization protocol could be adjusted and applied to an eccentric training program.

Design: Controlled laboratory study.

Setting: Controlled research laboratory.

Patients or Other Participants: Twenty-one sport science male students (age = 20.6 ± 1.5 years, height = 178.0 ± 4.0 cm, mass = 74.5 ± 9.1 kg).

Intervention(s): Participants performed 9 weeks of isotonic (n = 11) or isokinetic (n = 10) eccentric training of knee extensors that was designed so they would perform the same amount of angular work at the same mean angular velocity.

Main Outcome Measure(s): Angular work and angular velocity.

Results: The isotonic and isokinetic groups performed the same total amount of work (–185.2 ± 6.5 kJ and –184.4 ± 8.6 kJ, respectively) at the same angular velocity (21 ± 1°/s and 22°/s, respectively) with the same number of repetitions (8.0 and 8.0, respectively). Bland-Altman analysis showed that work (bias = 2.4%) and angular velocity (bias = 0.2%) were equalized over 9 weeks between the modes of training.

Conclusions: The procedure developed allows angular work and velocity to be standardized over 9 weeks of isotonic and isokinetic eccentric training of the knee extensors. This method could be useful in future studies in which researchers compare neuromuscular adaptations induced by each type of training mode with respect to rehabilitating patients after musculoskeletal injury.

Key Words: resistance exercise, muscle strength, knee extensors

Key Points

- Equalizing mechanical stimuli through a method previously developed on concentric muscle loading can be applied successfully to the study of long-term isotonic and isokinetic eccentric resistance training.
- This standardization procedure is valid and adaptable to progressive resistance exercise commonly used in strength training and rehabilitation.

Researchers have investigated many mechanical stimuli (eg, body weight movements, additional external load, constant velocity movements, elastic load) to increase muscle strength in healthy people or restore muscle function after injury. Most resistance-exercise training protocols induce muscle contractions against a constant external load (isotonic [IT]) or at a constant angular velocity (isokinetic [IK]).[1] The IK exercise is used in rehabilitation because it provides a safer environment for training muscle after injury (eg, accommodating resistance, fixed velocity training). Rigorously comparing strength development that IT and IK modes induce could help clinicians who progressively use IT loading in rehabilitation programs. Isotonic exercise stresses the neuromuscular system mainly at the beginning and end of the muscle contraction because of the mechanical leverage points throughout the range of motion (ROM), whereas with IK exercise, muscle contraction is performed against an accommodating resistance that theoretically allows a maximal contraction throughout the entire ROM at a preset constant velocity. Therefore, these 2 exercise modes induce different mechanical stimuli on the skeletal muscle system,[2] suggesting that each mode might induce specific adaptive processes of the neuromuscular system and the muscle-tendon unit and specific changes on torque-angle and torque-velocity relationships through different loading mechanisms.[3]

Attempts to determine the effects of IT and IK training on muscle strength have produced conflicting findings.[4–6] Some investigators have found that IT training is more effective than IK training for improving muscle strength,[6] whereas others have found opposite results[5] or no differences between modes of exercise.[4] These differences could be related to the difficulty of quantifying and normalizing the mechanical stimuli imposed by both training modes. The differences in input torque and angular velocity between modes suggest that IT and IK training induce different mechanical stimuli in terms of work and velocity. Remaud et al[7] developed an approach whereby the equalization of velocity and work performed during IT and IK concentric contractions of knee extensors was established. This standardization method has been adapted effectively for eccentric contractions using a test-retest design.[2] These investigators collectively have demonstrated that this standardization procedure can be applied to both concentric and eccentric muscle contractions. Although this method was established during 1 bout of exercise,[2,7] it also could be used in the long term with standardized IT and IK eccentric modes. Therefore, the purpose of our study was to examine whether the standardization protocol previously used could be adjusted adequately and applied effectively to a 9-week eccentric training program.

METHODS

Participants

Twenty-one healthy men without a history of knee injury volunteered to participate (Table 1). After a familiarization session, they were assigned to either the IT (n = 11) or IK (n = 10) training group. Both groups were homogeneous for age, height, mass, and maximal voluntary isometric contraction (MVIC). All participants provided written informed consent, and the study was approved by the local Scientific Committee of the University of Nantes.

Instrumentation

Every training session was performed on the same exercise dynamometer (Biodex System 3 Pro; Biodex Medical Systems, Shirley, NY) specifically modified to elicit IT and IK eccentric muscle loading using the same ergometer and positioning settings.[8] A plate-loaded resistance-training device was attached to the dynamometer. This apparatus allows application of constant load or constant velocity while the computerized dynamometer acquires the mechanical data. Mechanical signals from the dynamometer (ie, joint position, torque, angular velocity) were converted digitally at a frequency of 1000 Hz and low-pass filtered with the cutoff frequency of 20 Hz. The torque measurements were gravity and inertia corrected, and the mechanical work and mean angular velocity were calculated using a customized MATLAB program (The MathWorks, Inc, Natick, MA).[2]

Strength-Training Protocol

Participants performed eccentric contractions of the knee extensors of the right leg from 30° to 90° (0° = lever arm in horizontal position) of knee ROM. Ergometer settings and seat position were recorded during the familiarization session and reproduced for all training sessions. The maximal torque produced by the participants in MVIC of the knee extensors at 70° of knee angle and the maximal load they could lift concentrically after they were in IT mode (1RM) were determined on the dynamometer. After this session, participants were assigned randomly to the IT or IK training group.

The IT training group started the protocol 1 week before the IK group so we could program the IK training sessions based on IT group performances (see "Standardization Procedure for Angular Work and Velocity"). The training programs were built according to principles of resistance training[9] and a review of guidelines used during eccentric protocols.[1] All participants attended 20 training sessions in 9 weeks (Table 2) with 2 and then 3 sessions per week. The warmup at each session included 30 body-weight squats and 10 submaximal IT or IK eccentric contractions. The resistance-training exercise comprised 3 to 5 sets of eccentric contractions of the knee extensors with a 1-minute rest between sets. The IT group performed 8 repetitions per set at 100% to 120% of 1RM; the IK group, *n* maximal repetitions at 10°/s to 30°/s, where *n* represents the number of repetitions performed when the training modes were standardized. The training intensity and volume were increased (Table 2), and participants rested 1 week in the middle of the training period to optimize the effects of training.[9]

Standardization Procedure for Angular Work and Velocity

Repetitions were fixed at 8 per set for the IT group. One week before the IK sessions, the mean angular velocity ($\overline{\Omega}$) and the total amount of angular work (W) were calculated for each IT set. The amount of work the IK group had to perform the next week was based on the work the IT group performed. This value was balanced by the participant's MVIC (Equation 1) to adapt the training volume to his maximal strength.

$$W_{IKsubject} = \overline{W}_{ITgroup} \cdot \frac{MVIC_{IKparticipant}}{\overline{MVIC}_{IKgroup}}, \quad \text{(Equation 1).}$$

where $W_{IKparticipant}$ indicates the amount of work to perform in 1 set for a participant trained in IK mode (in Joules); $\overline{W}_{ITgroup}$, the mean amount of work in 1 set for the IT group (in Joules); $MVIC_{IKparticipant}$, the MVIC of the IK group participant (newton-meters); and $\overline{MVIC}_{IKgroup}$, the mean of MVIC of the IK group (newton-meters).

In IK mode, the dynamometer was configured to impose the same mean angular velocity calculated in the IT condition. For each set, the IK group achieved the same amount of angular work performed by the IT group (Equation 2). The IK set was

Table 1. Physical Characteristics of Participants (Mean ± SD)[a]

Group	Sample	Age, y	Height, cm	Mass, kg	Maximal Voluntary Isometric Torque, Nm
Isotonic	11	21.2 ± 1.7	176.9 ± 2.7	75.9 ± 8.8	278.0 ± 28.8
Isokinetic	10	20.2 ± 1.3	179.3 ± 5.2	73.9 ± 9.6	297.0 ± 41.8

[a] No differences were found between groups ($P > .05$).

Table 2. Training Design

	Week								
	1	2	3	4	5	6	7	8	9
Sessions	2	2	3	3	None	3	3	3	2
Sets	3	4	4	5	None	5	5	5	5
Repetitions									
Isotonic	8	8	8	8	None	8	8	8	8
Isokinetic	*n*[a]	*n*	*n*	*n*	None	*n*	*n*	*n*	*n*
Training load, % 1RM[b]									
Isotonic	100	100	120	120	None	120	120	120	120
Isokinetic	Maximal	Maximal	Maximal	Maximal	None	Maximal	Maximal	Maximal	Maximal
Angular velocity, Ω[c]									
Isotonic	$\overline{\Omega}_{IT}$	$\overline{\Omega}_{IT}$	$\overline{\Omega}_{IT}$	$\overline{\Omega}_{IT}$		$\overline{\Omega}_{IT}$	$\overline{\Omega}_{IT}$	$\overline{\Omega}_{IT}$	$\overline{\Omega}_{IT}$
Isokinetic	$\overline{\Omega}_{IK}$ similar to $\overline{\Omega}_{IT}$	$\overline{\Omega}_{IK}$ similar to $\overline{\Omega}_{IT}$	$\overline{\Omega}_{IK}$ similar to $\overline{\Omega}_{IT}$	$\overline{\Omega}_{IK}$ similar to $\overline{\Omega}_{IT}$	None	$\overline{\Omega}_{IK}$ similar to $\overline{\Omega}_{IT}$	$\overline{\Omega}_{IK}$ similar to $\overline{\Omega}_{IT}$	$\overline{\Omega}_{IK}$ similar to $\overline{\Omega}_{IT}$	$\overline{\Omega}_{IK}$ similar to $\overline{\Omega}_{IT}$

Abbreviations: Ω_{IK}, angular velocity preset for the isokinetic group; Ω_{IT}, angular velocity preset for the isotonic group.
[a] *n* indicates the number of repetitions performed when the training modes were standardized.
[b] Training load was fixed as a percentage of the maximal repetition (% 1RM) for the isotonic group.
[c] The isokinetic training program was performed at the same mean angular velocity (Ω) calculated in isotonic mode (Ω_{IT}).

terminated when the participant reached the preset work, which was displayed on the dynamometer.

$$\sum_{i=1}^{n} W_{IKrep_i} = W_{ITset}. \quad \text{(Equation 2)},$$

where W_{IKrep} indicates amount of work performed in an isokinetic repetition (in Joules); W_{ITset}, the amount of work performed in an isotonic set (in Joules).

Statistical Analysis

Normality of the data was tested using a Kolmogorov-Smirnov test. We used a *t* test to analyze the homogeneity of physical data between groups (Table 1). The level of concordance for the amount of angular work and mean angular velocity between groups was assessed for each set using Bland-Altman plots. According to Bland and Altman,[10] the *limits of agreement* were defined as the mean difference ± 1.96 standard deviations. A Wilcoxon signed rank test was used to analyze potential differences in the number of repetitions between modes. For all tests, the α level was set at .05.

RESULTS

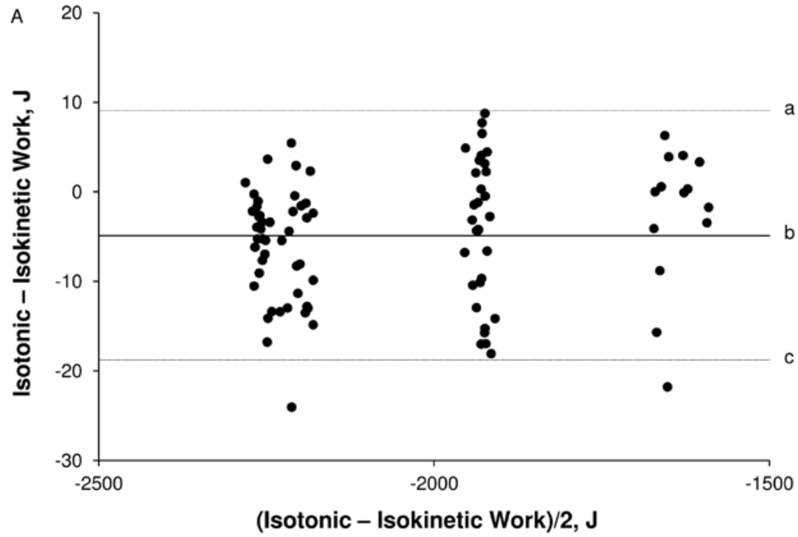
The Kolmogorov-Smirnov test confirmed the normality of the data (t_{90} range, 1.59–6.48, $P > .05$). The total amount of work performed was 185.2 ± 6.5 kJ for the IT group and 184.4 ± 8.6 kJ for the IK group over the 9-week training period. Both IT (21 ± 1°/s) and IK (22°/s) training programs were performed at the same mean angular velocity. The standardization procedure had a high concordance of the amount of work and the mean angular velocity between IT and IK eccentric training, as demonstrated by the low bias obtained for the total amount of angular work performed (δ = 2.4%) and the mean angular velocity (δ = 0.2%) (Figure). In these standardized conditions, we did not observe a difference for the number of repetitions performed in IT (8.0) and IK (8.0) training ($t_{90} = 0.40$, $P = .34$). We observed a smaller number of repetitions only for the first 2 weeks of training.

DISCUSSION

We aimed to standardize the mechanical stimuli induced by IT and IK eccentric training modes. Investigators[5,6] comparing IT and IK concentric training principally have standardized the training load by equalizing the number of sets and repetitions. Although this method does not quantify the exact amount of work performed, it constitutes an important factor regarding training outcomes.[5] Workload directly affects protein turnover and muscle structural modeling, resulting in muscular hypertrophy.[9] In parallel, training velocity influences recruitment, firing rate, and pattern discharge of motor units. Therefore, angular velocity affects training-induced neural adaptations.[11] Moreover, according to the training specificity principle,[9] the adaptations after eccentric training, which are mainly neural, are highly specific to the movement velocity. Thus, the different strength gains obtained in previous comparative studies could be imputable to the noncontrolled settings (eg, work and angular velocity) of training.

We applied a methodologic approach based on the equalization of amount of work and mean angular velocity developed in 1 exercise session[2,7] over a training period. Our results showed the effectiveness of the standardization procedure as revealed by the very low bias for the 2 controlled variables (ie, mean work, mean angular velocity). This process equalizes the contraction time between modes while the specificity of IT and IK training stimulus is conserved.[2] Even standardized, both training modes elicit different torque-angle and velocity-angle relations that could induce specific effects on the neuromuscular system. Therefore, the effects of standardized training would be attributable only to the biomechanical characteristics of each exercise mode. The standardization remains valid with the increase in training stimulus (ie, load, volume) and could be applied while respecting the progression principle of training. The constant follow-up of each training session allowed equalizing work and velocity continuously over the training period.

Both training programs involved the same mean number of repetitions. Guilhem et al[2] reported a smaller number of repetitions in IK mode when IT repetitions were performed at 100% of 1RM because of the maximal force produced throughout



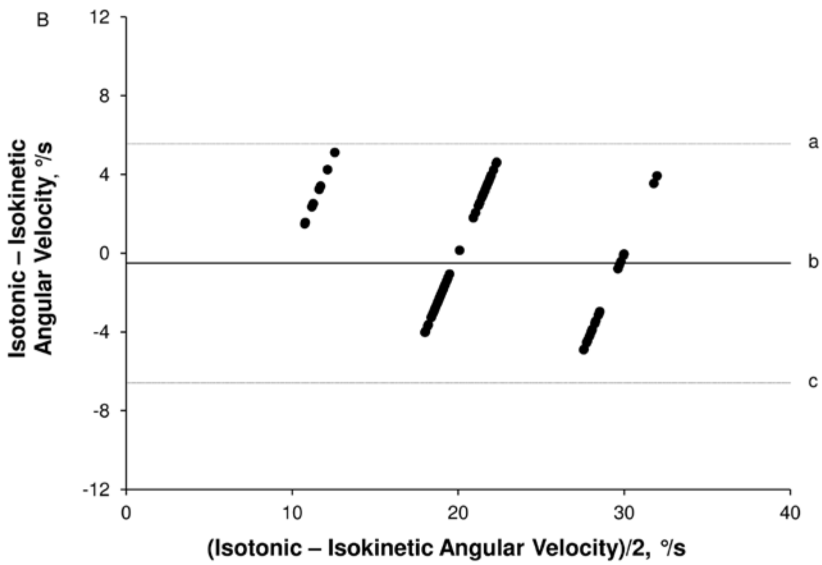


Figure. A, Bland-Altman plot for the amount of work between isotonic and isokinetic eccentric training (number of sets = 91). [a]Indicates upper confidence interval of 9.1. [b]Indicates bias of –4.9 J (2.4%). [c]Indicates lower confidence interval of –18.8. B, Bland-Altman plot for the angular velocity between isotonic and isokinetic eccentric training (number of sets = 91). [a]Indicates upper confidence interval of 5.6. [b]Indicates bias of –0.5°/s (0.4%). [c]Indicates lower confidence interval of –6.6.

ROM in the IK condition. To optimize the effect of training on muscle strength, supramaximal load (ie, 120% of 1RM) was applied in the IT mode. Applying overload in the IT condition generates higher torques and a greater amount of work in IT mode and involves the same number of repetitions in both modes.[2] The longer duration of this overload period might have eliminated potential differences during the first stage of training.

Methodologic Concerns and Limitations

The method we described could help build IT and IK eccentric training programs with the use of a commercially available exercise dynamometer. Our measurements of mechanical variables (torque, angle, velocity) required substantial material development, such as implementing a resistance-exercise device with the dynamometer and designing procedures for numeric data analysis. Nonetheless, this process could be reproduced on resistance-training devices equipped with position and torque sensors that provide similar information about mechanical characteristics. Moreover, the latest technologic developments provide native-instrumented machines that measure work and velocity during exercise sessions in the condition.

Practical Implications

Researchers[1,3] have reported that both IT and IK eccentric training effectively increase muscle strength and restore overall muscle function. However, it is not clear which protocol settings in terms of joint velocity, exercise load, or contraction mode most effectively increase muscle strength or treat functional disabilities (eg, tendinopathies). Our method could help clinicians adapt training or rehabilitation programs to maximize muscle strength gains.

CONCLUSIONS

The method of equalizing angular mechanical work and angular velocity adapted from previous work using a standardization procedure on eccentric muscle loading can be applied successfully to IK and IT resistance exercise over a prolonged training period. Our method allows comparison of similar training stimuli in terms of ROM, training load, and joint velocity that represent some of the major factors influencing neuromuscular training adaptations. Comparative studies based on this method could help determine the specific adaptive processes that these different training modes induce in muscle-tendon unit properties, neural drive, or muscle strength.

ACKNOWLEDGMENTS

This study was supported by grants from the Région des Pays de la Loire and the Réseau Recherche et Sport en Pays de la Loire (France). We thank the experts for their comments during the revision process.

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