Minimum rest period for strength recovery during a common isokinetic testing protocol

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ABSTRACT

PARCELL, A. C., R. D. SAWYER, V. A. TRICOLI, and T. D. CHINEVERE. Minimum rest period for strength recovery during a common isokinetic testing protocol. *Med. Sci. Sports Exerc.*, Vol. 34, No. 6, pp. 1018–1022, 2002. **Purpose:** The intent of this investigation was to determine the minimal time for a between sets rest period during a common isokinetic knee extension strength-testing protocol. Based on a review of the literature, a set was considered a group of four maximal coupled contractions at a specific velocity. **Methods:** Eleven normal, healthy college-age men underwent unilateral knee extension testing to determine their individual isokinetic peak torque at 60, 120, 180, 240, and 300°·s^{-1}. Velocities were administered in ascending order. Between sets, rest periods of 15, 60, 180, and 300 s were assigned to subjects in a counterbalanced fashion. **Results:** There were no differences in peak torque at the beginning velocity of 60°·s^{-1} among any of the rest periods. At 120°·s^{-1}, peak torque production during the 15-s rest period trial was similar to 60 s but lower than 180 and 300 s. Peak torques at 180, 240, and 300°·s^{-1} produced during the 15-s rest period test were significantly lower than measured torques at the same velocities during the 60, 180, and 300-s rest period tests ($P < 0.05$). There were no differences in peak torque production between the 60, 180, and 300-s rest period tests. **Conclusion:** These data demonstrate that during a common isokinetic strength testing protocol a between set rest period of at least 60 s is sufficient for recovery before the next test set. **Key Words:** FATIGUE, KNEE EXTENSION, REST INTERVAL

The introduction of isokinetic testing devices provided for evaluation of contractile function at constant angular velocities during maximal contractions. This type of strength evaluation has been employed to characterize function in different populations (4,26,31,38), assess functional decrements after periods of inactivity (2,18,19), and to describe contractile changes in response to training (9,10,11,30). In spite of its wide use, there is no apparent convention as to testing protocols (Table 1).

Studies utilizing isokinetic testing generally require subjects to perform two to four maximal contractions in succession at three to five different velocities. Usually these velocities are administered in ascending order, although some investigators have chosen to randomize velocity order (1,2,4,9–11,13,14,18,24,26,30,38,41) (Table 1). Further examination of testing protocols revealed that the rest period provided between test sets is very inconsistent. Rest times range from 30 s to 3 min in length, and in many cases investigators fail to report rest times (Table 1). In light of the significant influence of rest on recovery of contractile function after maximal contractions, this discrepancy among reports raises concern when evaluating reported findings.

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Data currently available show that rest intervals during isokinetic testing influence strength during subsequent test sets (32,33,39). However, these studies used testing protocols considerably different from those commonly prescribed during isokinetic strength evaluation in a laboratory setting (Table 1). It was the purpose of this study to determine the minimal time for a between sets rest period during a common isokinetic leg extension strength-testing protocol.

In the present investigation, between-set rest periods of 15, 60, 120, 180, and 300 s were chosen based on review of the literature and pilot testing in our laboratory. A rest period of 15 s was selected with the intent to clearly demonstrate the effects of fatigue on force production. The remaining rest periods were included to evaluate time intervals that are common in this type of strength testing (Table 1). A 30-s rest period was evaluated in pilot testing and demonstrated similarities to the 15-s rest interval. In light of these similarities and considering that 30 s of rest is unlikely to be utilized by most investigators for experimental testing of maximal force production, this interval was excluded from final evaluation. It was hypothesized based on total contraction time employed in the current protocol that 60 s would provide sufficient rest between contraction sets.

METHODS

Subjects. Eleven men, age 30 ± 1 yr, height 181.9 ± 1.6 cm, and weight 81.2 ± 3.5 kg (mean ±SE), volunteered

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TABLE 1. Overview of isokinetic strength-testing protocols.

Author	Velocities Tested ($°\cdot s^{-1}$)	Contractions/Velocity	Order of Contractions	Rest Period Length	Torque Measurement
Aagaard and Andersen (1)	30, 120, 240	6–7	Randomized	Not reported	Peak torque
Berg et al. (2)	30, 60, 90, 120, 180	2	Ascending	2 min	Peak torque
Bilcheck et al. (4)	30, 120	4	Randomized	30 s	Peak torque
Caiozzo et al. (9)	50, 96, 144, 190, 240, 288	4–7	Ascending	10 s per contraction	Peak torque
Carroll et al. (10)	60, 180, 300, 500	5	Mixed	1 min	Angle specific
Coyle et al. (11)	60, 180, 300	2–3	Ascending	Not reported	Peak torque
Delitto et al. (13)	60, 120, 180	10	Ascending	3 min	Peak torque
Dudley et al. (14)	30, 100, 170, 240	3	Ascending	1 min	Angle specific
Germain et al. (18)	180, 240, 300, 120, 60, 30	4	Mixed	90 s	Peak torque
Klitgaard et al. (24)	40–800	3	Ascending	Not reported	Peak torque
Larsson et al. (26)	30, 60, 120, 180	2	Ascending	Not reported	Angle specific
Narici et al. (30)	60, 120, 180, 240, 300	Not reported	Ascending	Not reported	Angle specific
Thorstensson et al. (38)	15, 30, 60, 90, 180	2	Randomized	Not reported	Peak torque
Veldhuizen et al. (41)	60, 120, 180, 240, 300	5	Ascending	Not reported	Peak torque

to participate. Subjects reported to the lab on two separate days for familiarization sessions to minimize the effects of learning on torque production during the isokinetic tests. All subjects were recreationally active, but none were participating in a regular exercise-training program. The study was approved by the university human subjects review board, and all subjects provided written informed consent before participation.

Experimental procedures. To test the effect of rest period length on isokinetic knee extensor torque, subjects performed a standard isokinetic protocol on four separate days with at least 48 h between test sessions. During each of the four test sessions, the subject completed the isokinetic protocol with either 15, 60, 180, or 300 s of rest between sets. The order of the rest period conditions was counterbalanced. Subjects were instructed to abstain from exercise 24 h before each testing session.

Familiarization. Subjects were fitted on an isokinetic dynamometer (Biodex System 3, Biodex Medical Systems, Newark, CA) with the axis of rotation of the dynamometer arm oriented with the axis of rotation of the right knee. Belts were used to secure the thigh, pelvis, and trunk to the dynamometer chair to prevent additional body movement. The chair and dynamometer settings were recorded to ensure the same positioning for all four of the experimental tests. For familiarization with isokinetic contraction velocities, subjects performed four maximal repetitions at 60, 180, and $300°\cdot s^{-1}$ with 3-min rest between sets.

Testing. Immediately before the two familiarization and four experimental testing sessions, a standard cycling and knee extension warm-up protocol was performed. Subjects exercised on a cycle ergometer at 100 W for 5 min. After the cycle warm-up, subjects were seated on the isokinetic dynamometer and actively warmed-up the involved quadriceps muscles by performing three to four submaximal knee extension repetitions (50–70% of maximum, subjective) at 60, 120, 180, 240, and $300°\cdot s^{-1}$.

For all testing sessions, subjects performed maximal isokinetic contractions with a standard protocol from slow to fast velocity (60, 120, 180, 240, and $300°\cdot s^{-1}$). A counterbalanced administration of velocities was considered by the authors. However, assessment of the published literature demonstrated that the majority of researchers using isokinetic strength testing administer velocities in ascending order; thus, we opted for a testing protocol which accurately reflected prevalent methodologies.

Subjects began each set with the right leg at a 90° angle and performed four maximal knee extension contractions in succession at each velocity interspersed with the assigned rest period for that trial. Subjects were instructed to contract maximally and maintain the contraction through the full range of motion. After each maximal contraction, subjects allowed the limb to passively return to a 90° knee angle. Flexion velocity was set at $300°\cdot s^{-1}$, essentially offering no resistance to subjects during knee flexion. Subjects were required to bring the limb to a complete stop before the next maximal contraction to prevent preload on the quadriceps. Each velocity tested was considered a set, and four repetitions were performed per set. Angle-specific torque measures may provide insight into biomechanical, neural, and mechanical factors associated with whole-muscle contraction. However, based on the cross-sectional nature of this study, it was the opinion of the authors that the influence of fatigue on all of these factors would be adequately represented by measurement of peak torque regardless of the knee angle; therefore, the highest torque value during each set was selected for analysis. Between sets, subjects rested either 15, 60, 180, or 300 s, depending on the assigned rest period.

Statistics. The study was a 5×5 repeated measures design with the factors of rest period and velocity as the independent variables. The dependent variable of peak torque was analyzed for each condition using a two-factor ANOVA with repeated measures on rest period and velocity. In the event of interaction, a Scheffe *post hoc* analysis was used to make all pairwise comparisons to locate significant differences. The level of statistical significance was set at $P < 0.05$. Means are presented $\pm$ SE.

RESULTS

Analysis of the data revealed a main effect of velocity ($F=12.30$, $P = 0.0000$) on torque production regardless of rest period length (Fig. 1). Rest period also demonstrated a main effect ($F=307.62$, $P = 0.0000$), and a significant

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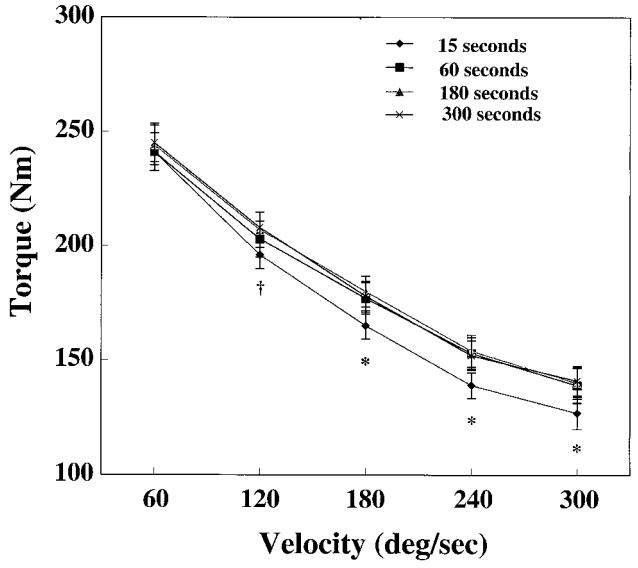

FIGURE 1—Torque-velocity curves from maximal voluntary isokinetic contractions in response to four different between sets rest periods; † denotes 15 s trial different from 180 and 300 s trials ($P < 0.05$); * denotes 15 s trial different from all other trials ($P < 0.05$).

interaction was noted between the variables of velocity and rest period ($F=3.48$, $P = 0.0002$).

All subjects began experimental testing at $60°\cdot s^{-1}$. The Scheffe *post hoc* analyses of cell means revealed no differences at this beginning velocity among any of the rest period trials ($P > 0.05$). At $120°\cdot s^{-1}$, there was no difference between the 15- and 60-s rest period groups; however, torque produced during the 15-s rest period was significantly lower ($P < 0.05$) when compared with the 180- and 300-s rest period groups. At the remaining velocities, 180, 240, and $300°\cdot s^{-1}$, peak torque during the 15-s rest period trial was less than that recorded during the 60-, 180-, and 300-s rest period trials ($P < 0.05$). There were no differences in peak torque values within all velocities tested among the 60-, 180-, and 300-s rest period trials.

DISCUSSION

Whole-muscle function testing in human subjects is a widely used criterion measure to characterize and/or evaluate different populations. The development of isokinetic measurement devices provided for the assessment of muscular strength at various contractile velocities. Isokinetic devices are commonly used in the fields of exercise science and sports medicine for evaluating adaptations to training and progression of rehabilitation, and as a training modality for rehabilitating subjects. However, a large variation in testing procedures is apparent when reviewing the literature (Table 1).

It is well established that repeated contractions result in muscular fatigue, usually expressed as a reduction in force producing capacity. This reduced strength has its basis primarily in metabolic and mechanical factors (16). In an acute setting, repeated contractions have resulted in depletion of fuel sources, accumulation of metabolic byproducts, and a concomitant reduction in force production (5,6,29). Investigations designed to assess the acute neural contributions to muscular fatigue during repeated contractions have not shown failure of the nervous system (20,37). On the contrary, in the short-term, the nervous system responds with increased motor unit recruitment to offset the negative effects of metabolic byproduct accumulation (3,25,42).

Adequate recovery, as in a rest period after muscle contraction, will result in a return to a normal internal milieu and a restoration of muscular strength. If the principle of fatigue is not addressed during strength testing, then latter sets of a testing protocol will most likely underestimate the maximal strength of a subject. A reduction in maximal repetitions or adequate rest between sets of maximal isokinetic contractions would prevent such errors.

A brief review of the literature revealed that a large number of studies that utilize isokinetic strength testing to evaluate contractile function fail to report the period of rest between sets during testing. Some authors merely stated that "adequate" rest was provided without description or definition (Table 1). Those investigations disclosing rest periods demonstrated a range in between sets rest periods from 30 s to 3 min, whereas some provided subjects with "brief" rests between contractions (9,26). It is clear that there is not a consensus with regard to between sets recovery periods during isokinetic testing.

In the current study, a protocol consisting of four successive maximal contractions at five velocities in ascending order was administered. This protocol was selected due to its similarity to isokinetic strength-testing protocols generally described in the literature (Table 1). In the present subjects, the significant decline in torque with increasing velocities clearly demonstrates the force-velocity relationship in human skeletal muscle. This phenomenon has been shown to be influenced by muscle fiber type (38) and physical training (11). With regard to rest period, subjects were given either 15, 60, 180, or 300 s of rest between test sets. With the exception of $60°\cdot s^{-1}$, analyses revealed that a rest period of only 15 s resulted in a significant decline in force production when compared with peak torque produced during the 60-, 180-, and 300-s rest period trials. There were no differences in torque production at any velocity among the 60-, 180-, and 300-s rest period trials. It should be noted, however, that recovery intervals may be lower if fewer contractions per set are performed. Nevertheless, the results of this study clearly demonstrate that peak torque production during a common isokinetic strength testing protocol is similar when subjects are provided a between sets rest period of either 1, 3, or 5 min.

In research conducted by Pincivero et al. (33), subjects performed four sets of 10 maximal isokinetic contractions at $90°\cdot s^{-1}$ with sets separated by 40- or 160-s rest periods. Their results showed a significant decline in peak torque, total work, and average work for the 40-s rest period group, whereas the same performance variables were unaffected in the 160-s group. An abstract published by Touey and associates (39) detailed a more involved protocol. Touey et al.'s subjects completed four sets of 10 maximal contractions at

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either 60 or 180°·s^{-1} with rest periods of 30, 60, 120 or 240 s. For the variables of peak torque and total work, rest periods of 30 and 60 s caused manifestations of fatigue in subjects. When subjects were allowed either 120 or 240 s of rest, they were able to complete test sets without declines in contractile function. These studies clearly show the effect of inadequate rest during maximal isokinetic strength testing. However, the number of repetitive contractions performed in these studies is different from those generally described in the literature (Table 1).

The basis for strength decline during short-duration, high-intensity exercise, such as the 15-s rest period trial, is related to fuel substrate availability and metabolic byproduct accumulation (22,23). During repeated bouts of high-intensity exercise, inadequate rest results in a reduction of phosphocreatine stores and a rapid accumulation of hydrogen ion (7,21,35). Hydrogen ion interrupts the calcium/troponin interaction that precedes crossbridge formation, and as a result has been shown to attenuate the force producing capacity of skeletal muscle (28). Metabolically, increasing concentrations of hydrogen ions may reduce glycolytic rates due to allosteric inhibition of the enzyme phosphofructokinase (36,40). These combined effects of hydrogen ion present obvious limitations to force production in skeletal muscle.

The ATP demands of skeletal muscle are supported primarily by the phosphagen and glycolytic systems during high-intensity exercise (5,6,8,15,17,23,27,34). Hirvonen and colleagues (22) studied muscle metabolism and fatigue characteristics during sprints of 100, 200, 300, and 400 m. Their results demonstrated that the greatest decline in creatine phosphate (−47.5%) occurred during the first 100 m. This was accompanied by a 3.4 mmol·L^{-1} increase in blood lactate concentrations. At 200 m, running speed started to decline. The authors attributed this reduction in running velocity to the rapid depletion in phosphagen system constituents and build-up of hydrogen ion.

Dawson et al. (12) had subjects perform five sprint bouts of 6 s in duration separated by 30 s of rest. Phosphocreatine values were 27% of resting levels after the exercise period. After 30 s and 3 min of rest, phosphocreatine levels had returned to 45 and 84% of resting values, respectively. After a single 30-s maximal sprint bout, Bogdanis et al. (5) measured phosphocreatine concentration at 65% of resting values after 90 s of rest. Results from these studies suggest the negative effects of fuel depletion and byproduct accumulation on work performance may be reduced when sufficient recovery time is allowed so as to provide for resynthesis of fuel substrates and normalization of pH (5,12,32). Contraction times and total work was considerably less in the current protocol (~2–6 s per set) compared with the studies above. However, Gaitanos and colleagues (17) conducted a maximal-exercise protocol that may be comparable to the efforts of the present subjects. Gaitanos et al. had subjects cycle at maximal intensity for 6 s. A muscle biopsy was obtained before and immediately after the sprint bout. They measured a 57% decline (76.5 ± 7.2 to 32.9 ± 2.6 mmol·kg^{-1}) in muscle phosphocreatine concentrations as well as a 653% increase (3.8 ± 1.1 to 28.6 ± 5.7 mmol·kg^{-1}) in muscle lactate concentrations. The large changes in lactate would indirectly indicate a considerable buildup of hydrogen ion within the muscle cells. These represent remarkable changes in the metabolic status of the muscle after only a very brief period of time and support the notion that even the brief maximal efforts performed by the current subjects may have indeed been sufficient to produce changes in pH and fuel depletion to significantly reduce knee extension torque production.

In the present subjects, maximal contractions with only 15 s of rest between velocity sets likely resulted in reduced phosphocreatine stores and an accumulation of hydrogen ion, both of which would contribute to the observed declines in force production (17). The current data demonstrate that 60 s of rest was sufficient to allow recovery of force producing capacity. Though not measured, it would appear that changes in phosphocreatine availability and, to a lesser extent, pH changes were not limiting to performance as demonstrated by peak torque values. According to previous research, 60 s may not result in complete recovery of fuel stores (5,12). However, with the number of contractions performed by our subjects, 60 s is sufficient for maintenance of force production.

Rest has a critical influence on tension generation in human skeletal muscle. Adequate recovery after maximal contractions is of primary importance when evaluating whole muscle functional characteristics in human subjects. In many cases, the variable of rest during isokinetic testing has been overlooked or underreported. In the current subjects, 15 s of between sets rest resulted in significant reductions in knee extension torque production during successive test velocities (5, 8, 10, and 10% at velocities of 120, 180, 240, and 300°·s^{-1}, respectively, $P < 0.05$) when compared with rest periods of 60, 180, and 300 s. The findings of this investigation present strong evidence that a between sets rest period of 60 s during a common isokinetic knee extension testing protocol (4 sets, 2–6 s per set) is sufficient for the recovery of force producing capacity in normal healthy subjects. These data provide a conclusive standard for future isokinetic strength testing protocols and may serve to reduce methodological discrepancies in the research literature.

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