Influence of Cadence on Muscular Performance During Push-up and Pull-up Exercise

Peter F. LaChance and Tibor Hortobagyi

Department of Physical Education, U.S. Military Academy, West Point, New York 10996-1694; Human Performance Laboratory, East Carolina University, Greenville, North Carolina 27858.

Reference Data

ABSTRACT

The acute effects of different cadences on performance during maximal effort push-up and pull-up exercise were evaluated. Subjects, 75 college age males, completed a within-subjects balanced design involving three cadences (fast self-paced, 2/2, and 2/4). For each condition they completed as many repetitions as possible. The number of repetitions, work, and power output differed for each cadence and exercise mode, and interactions occurred between modes for repetitions, work, and power output. During self-paced pull-ups, subjects completed 96% more repetitions and work, in 16% less time, and attained 131% greater power output than during 2/4 exercise. Likewise, during self-paced push-ups they performed 145% more repetitions and work, in 51% less time, and attained 399% greater power output than during 2/4 exercise. Repetitions, work, and power output scores for the 2/2 cadence were midway between those for the self-paced and 2/4 cadences for each mode. The findings indicate that the amount and rate of work performed during a single bout of exercise depends on the exercise cadence.

Key Words: resistance training, high intensity, repetition maximums, fatigue

Introduction

Specificity is an important principle of resistance training. The principle of specificity dictates that conditioning exercise should be prescribed and performed only after careful identification of the purpose and goals of training (1, 4, 5, 8, 11). From a muscular fitness perspective, potential goals to be considered include the development of strength, size, speed, muscular endurance, and power output.

In the domain of resistance training, the specificity concept for exercise cadence has often been disregarded. For example, Nautilus Sports Medicine (12), Darden (2, 3), Riley (13), and a number of strength conditioning coaches continue to recommend that "2/4" exercise cadences be universally prescribed, regardless of the mode or goals of training (2/4 represents a 2-s concentric and 4-s eccentric action during 6-s repetitions). Considering the literature cited above, this prescription overlooks potential differences in training goals and the ramifications of the specificity principle.

The cadence and corresponding concentric/eccentric velocity used during training may well affect the volume and power output of exercise that can be performed. Theoretically, variations in the amount and rate of performance imply differences in the acute and chronic exercise stress, and therefore potential long-term adaptations. There appears to be limited research describing the acute effects of cadence on performance. Therefore the purpose of this study was to evaluate the influence of three commonly used cadences on maximal muscular performance during exercise. This design allowed for an assessment of the maximal number of repetitions, work, and power output during a single bout of maximal effort exercise at each cadence.

Methods

Two calisthenic exercises that are traditionally employed in a variety of physical conditioning and field testing situations were selected for evaluation. Subjects were tested for the maximum number of repetitions during push-ups and pull-ups at each of three cadences over 6 test days. The sequence of testing was randomized across subjects. Test sessions were separated by 48 to 72 hrs.

After being informed of the purpose, risks, and procedures, 75 moderately trained college age men from three strength development classes volunteered to participate. Their average stature (Ht) and body mass (BM) were 1.74 (±0.09) m and 75.9 (±21.0) kg.

Exercises

Push-ups. Push-ups were performed using the standards outlined in the Army Field Manual (FM 21-20). From a front leaning rest position, hands were placed
approximately shoulder-width apart, and feet up to 0.3 m apart. During exercise, the subjects maintained a rigid body position from the ankles to the shoulders. The top of the range of motion (ROM) corresponded to complete extension of the arms while the bottom of the ROM occurred when the chest was lowered to the floor at ~90° elbow flexion. The surface for all tests was a poured solid rubber floor. The load and range of motion for the push-up were estimated to be 66% BM and 0.4 m, respectively. The 66% BM value was determined during a pilot study as the static load exerted on a balance scale at the hands during the front leaning rest position of the push-up. The ROM of 0.4 m was a constant estimated as the average ROM across subjects.

**Pull-ups.** Subjects performed pull-ups with hands approximately shoulder-width apart and palms facing away. The top of the ROM corresponded to the point when the hyoid bone was pulled up to the level of the bar, as viewed by the evaluator. The bottom of the ROM occurred when the elbows were fully extended. The steel high-bar was 0.09 m in circumference and 1.82 m long, and was suspended 2.43 m above the ground. The load and ROM for the pull-up were estimated and assumed to be 95% BM (assuming the mass of the hands and forearms equals 0.05% BM) and 0.5 m, respectively. The ROM of 0.5 m during the pull-up was a constant estimated as the average ROM across subjects.

**Cadences.** Self-paced, 2/2, and 2/4 cadences were evaluated. During the self-paced cadence, subjects exercised at a fast pace. The 2/2 and 2/4 cadences were accurately timed with a hand-held digital LED clock and verbally signaled to the subjects. The 2/2 cadence represented a 2-s up (concentric) phase immediately followed by a 2-s down (eccentric) phase. The 2/4 cadence represented a 2-s concentric and 4-s eccentric phase. To promote a constant rate of motion, the midpoint of the concentric and eccentric actions occurred at the end of the first and third counts for 2/2 cadences, and at the end of the first and fourth counts for 2/4 cadences, respectively. The total repetition time for 2/2 and 2/4 cadences were exactly 4 and 6 s.

**Testing.** Groups of approximately 20 subjects were paired with a counter and simultaneously performed the exercises while being observed by two testers. Subjects were extremely familiar with the procedure and standards involved during the push-up and pull-up. Exercise bouts were terminated once the subject failed to complete a full range of motion or maintain the prescribed cadence. Each set was performed at maximal effort. Upon completion of each test, repetitions and times were recorded on a score sheet for later data analysis. The reliability of these tests is discussed below.

**Calculations**
For the purposes of simplicity, average concentric work and power output were calculated as shown by the following examples for an 80-kg subject completing 10 pull-ups and 50 push-ups:

**Pull-up concentric work = reps × ROM × (0.95 × BM) × g**
- e.g., = 10 reps × (0.5 m ROM/rep) × (0.95 × 80 kg) × 9.8066 m/s²
  = 380 kg·m × 9.8066 m/s²
  = 3,726 J = 3.726 KJ

**Push-up concentric work = reps × ROM × (0.66 × BM) × g**
- e.g., = 50 reps × (0.4 m ROM/rep) × (0.66 × 80 kg) × 9.8066 m/s²
  = 1056 kg·m × 9.8066 m/s²
  = 10,356 J = 10.356 KJ

Note: g = acceleration due to gravity = 9.8066 m/s²

Average concentric power output (W) during the entire set of push-up and pull-up exercises was calculated as concentric work divided by work duration.
- e.g., \([10,356 \text{ KJ}} / 200 \text{s}) = 51.78 \text{ W}

The criterion measures calculated for both exercises at the three cadences were (a) total number of repetitions, (b) total concentric work in KJ, (c) work duration in s, and (d) average concentric power output in W. During a pilot study, day-to-day reliabilities exceeded r = 0.87 for the various criterion measures (10). Maximal repetition scores during the self-paced condition in this study were slightly lower but were highly correlated with push-up scores reported during biannual physical fitness tests (64.1 vs. 68.5 reps; r = 0.76) and height/weight/pull-up surveys (11.2 vs. 12.1 reps; r = 0.88) administered 3 weeks earlier during the same semester.

**Statistics.** The mean performance scores for the three cadences during two exercise modes were compared with a repeated measures analysis of variance (ANOVA). Repeated measures ANOVAs were also performed for each mode independently. When a significant F ratio was encountered, a Scheffé post hoc contrast was employed to detect significant differences among the means. The probability level was set at p < 0.05. Correlations between BM, Ht, repetitions, work, and power output were also computed for each mode to determine whether the effects of cadence were influenced by body size and stature.

**Results and Discussion**
The analysis of variance revealed significant differences among cadences for all variables and each mode (Table 1). Work and exercise duration scores were directly proportional to repetitions during 2/2 and 2/4 exercise, since they are linear transformations of each other. During self-paced pull-up exercise, subjects performed 5.5 (96%) more repetitions, did 1.95 KJ (96%) more work, worked 5.4 s (16%) less, and attained 77.5 W (131%) more power than during the 2/4 cadence (p < 0.05). Similarly, during
self-paced push-up exercise, subjects performed 37.7 (43%) more repetitions, did 7.52 KJ (43%) more work, worked 81.4 s (51%) less, and attained 131.4 W (399%) more power than during 2/4 exercise (p < 0.05). The repetitions, work, and power output scores for the 2/2 cadence were midway between the self-paced and 2/4 cadences for each mode (p < 0.05).

The relationships observed between the anthropometric and selected performance data are summarized in Tables 2 and 3. BM and Ht did not correlate significantly with either pull-up (r < 0.27) or push-up (r < 0.34) repetitions at any cadence. Repetitions for pull-ups during self-paced, 2/2, and 2/4 cadences were highly interrelated and ranged between r = 0.86 and r = 0.89. Likewise, repetitions for push-ups during 2/2 and 2/4 cadences were also highly related (r = 0.83). Conversely, repetitions for push-ups during self-paced cadences were only moderately related to performances during 2/2 (r = 0.53) and 2/4 (r = 0.57) cadences.

The results of this study indicate that the cadence at which exercises are performed influences muscular performance. For both exercises, faster cadences permitted significantly more repetitions, greater work, and higher power outputs than slower cadences. The effects of cadence were independent of height and body mass.

In contrast to the specificity concept, there has been commercial promotion of 2/4 (12) and even “super-slow” exercise ranging from 4/10 cadences to the 60-s repetition for enhancing muscle size, strength, endurance, and power output (7). Because these variables represent independent components of muscular fitness, their development theoretically requires a different set of conditions in terms of force (load), velocity (cadence), and duration (repetitions) of exercise. Therefore one cannot expect simultaneous or optimal improvement in all components of muscular fitness as a result of a single resistance exercise condition. The notion that the speed or rate of exercise is not important goes against the specificity principle.

Performance during the self-paced cadences exceeded that during the 2/2 and 2/4 cadences for both push-ups and pull-ups. This occurred despite differences in the exercise load and ROM, and the rate at which self-paced repetitions were performed. For the self-paced push-up, which involved a lighter load (66% vs. 95% BM) and smaller range of motion than the pull-up (0.4 vs. 0.5 m), the time required to complete a repetition averaged 1.2 s. On the other hand, the duration during self-paced pull-ups averaged 2.6 s per repetition. The 1.4-s time differential might be the result of the heavier load and larger range of motion during pull-up exercise.

Although the criteria for terminating exercise was the failure to maintain the prescribed cadence (power output), the reasons may be different during push-ups and pull-ups. For each cadence the corresponding number of repetitions during push-ups exceeded that during pull-ups by more than 460%. Relatively speaking, maximal performance and subsequent fatigue during higher repetition push-up exercise may be more related to limitations in anaerobic capacity than to muscular strength-endurance. On the other hand, performance and set termination during lower repetition pull-up exercise may be more related to initial strength-endurance levels than to one’s anaerobic capacity. Regardless of the mechanism of fatigue, slower cadences appear to limit the amount of work that can be completed in a single bout of exercise.

The implications from the work values are that caloric expenditures are influenced by the exercise cadence.
Although there is a direct and positive relationship between external work and caloric expenditure, absolute differences in energy expenditures between cadences can only be confirmed by gas analysis or direct calorimetry. Estimated caloric expenditures during 2/2 and 2/4 push-ups would, respectively, require 25 and 49% more exercise time to expend an equivalent amount of energy as that expended during self-paced exercise. Even when assuming large contributions from stored elastic energy during self-paced push-up exercise, the calculated values for energy expenditure are greater per unit of time during faster cadences. Independent of the mode of exercise, energy expenditure differences, as a function of cadence, might be of considerable significance if the goals of training are either improved anaerobic power or enhanced body composition.

Differences in performance as a function of cadence may be partially explained by the effect of muscular activation on blood flow (6, 14). Occlusion of blood flow occurs during concentric actions and to a lesser extent eccentric actions, perhaps because fewer motor units are activated. The amount and duration of occlusion may be exacerbated if the exerciser pauses isometrically between concentric and eccentric actions or protracts the exercise cadence. Any occlusion would reduce O2 delivery and lactate and H+ removal (factors known to impair rate limiting steps in anaerobic glycolysis). As a consequence, slower cadences might limit the amount and duration that the fatigable fast twitch anaerobic fibers can contribute to movement, thereby limiting total work during a single bout of exercise. While slower cadences may be relatively effective for slow twitch fiber hypertrophy or increasing isometric endurance, slow speed repetitions and pausing are not likely to be universally effective for developing all other components of muscular fitness (9).

**Practical Applications**

Although the present study is only cross-sectional in nature, it does illustrate the effect of cadence over variables that have been shown to influence the quality and quantity of the training stimulus. One expectation would be that the differences in the exercise cadences, and therefore in work and power output, would involve, stress, and develop different neuromuscular mechanisms.

While quality repetitions are important, slowing the cadence beyond 4 s per repetition may not diminish variations in force output (16). On the basis of our repetition and correlation data, one could argue that a slower cadence (e.g., 2 to 3 s per repetition vs. 1.2) during the self-paced push-ups would maintain loading across the full ROM, and yet still result in greater performance than that during 2/2 and 2/4 cadences. Integration of faster exercise may be the only controllable opportunity an athlete has to expose and prepare the “trainable” muscles, ligaments, and bones for the inherent stress of physical activity (15).

The results of this study do not suggest that all-out ballistic exercise is necessary or even appropriate for improving all components of fitness. But they may have implications for other forms of resistance training such as during machine and free-weight exercise. However, these recommendations cannot extend to all ages and populations. Resistance training programs for novice, prepubescent, and geriatric populations should be initiated and maintained with slow-speed nonballistic exercise. From another perspective, absolute or blanket recommendations about specific cadences fail to consider that the physiological ROM, maximal speed, and time to maximal tension, among other variables, are different between muscle groups, exercises, and individuals.

**References**