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REVİEW ARTICLE

Effect of Movement Tempo During Resistance Training on Hypertrophy and Muscular Fitness: A Narrative Literature Review

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Abstract

Although many studies have demonstrated whether movement tempo, a training variable during resistance exercise, has an effect on muscle performance, there are still gray areas related to muscle hypertrophy and muscular fitness in different populations. The aim of this narrative systematic review was to investigate the effect of movement tempo on muscular performance such as maximal strength, skeletal muscle hypertrophy, muscle power and muscular endurance in resistance training performed at specific frequencies. Three electronic databases were searched using terms related to movement tempo and resistance training. The included studies were those published in English using randomized and non-randomized comparative dynamic resistance exercise interventions in healthy adults. The results suggest that changing the tempo of movement during resistance training may have an effect on muscle hypertrophy, but the results are not conclusive. There are conflicting research results, although faster tempos seem to be advantageous in terms of power outcomes at different movement tempos. More studies are needed to evaluate muscular endurance performance in terms of movement tempo. Differences in the size of the muscles studied, the structure of the training programs, and the standardization of the experimental approach and data collection tools used may partially explain the inconsistency in the results between tempos in different contraction phases or in the same contraction phases.

Keywords: Movement Tempo, Muscular Fitness, Resistance Training

INTRODUCTION

Resistance exercise program is widely used by athletes and sedentary individuals to improve physical fitness components. When designing a resistance exercise program, there are some acute training variables that can be manipulated to adapt the targeted fitness component (Baechle, Earle, & Wathen, 2008). Among the physical fitness components, resistance training is the most important type of exercise to achieve muscular fitness. The manipulation of exercise program variables is important in order to obtain a maximal muscular performance response after a resistance exercise program. When programming resistance training, the primary training variables include number of sets, number of repetitions, rest between sets, training volume, exercise selection, intensity (load) and movement tempo (Bird, Tarpenning, & Marino, 2005). Among these variables, movement tempo is usually the most ignored variable. Repetition rate in resistance exercises is often defined as the tempo of a resistance exercise (Schoenfeld, Ogborn, & Krieger, 2015). The term tempo refers to the speed at which each repetition is performed. This tempo of movement can be conscious and unconscious. To illustrate this, a slow tempo may occur involuntarily during

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resistance training, which is unintentional due to a heavy load or fatigue (Mookerjee & Ratamess, 1999). In contrast, a voluntarily slow tempo can be used when the load is light enough to be controlled and fatigue does not affect one's ability to control movement speed. Regardless of whether movement tempo is voluntary or involuntary, movement tempo in resistance exercise is often communicated as a training variable using a series of digits where each digit describes the duration of a particular phase of movement (Wikl et al., 2021). For example, the movement tempo variable 2:0:X:0 refers to the eccentric, isometric, concentric and isometric phases in a resistance workout. 2:0:X:0 indicates an eccentric phase of two seconds, no intentional isometric pause during the transition phase, the maximum possible movement tempo during the concentric phase, and no pause between the completion of the concentric phase and the beginning of the next eccentric phase. As we mentioned before, since movement tempo is also classified as voluntary, V:0:V:0 can be used in training programs to express the use of voluntary speed. In addition, X:0:X:0 is used as a movement tempo variable in explosive strength training at the maximum possible speed with the load worked at the time of exercise. Some sources have suggested the use of 3-digit numbers for the repetition rate variable, which represents the sum of concentric, eccentric and isometric components of a repetition (Ogborn and Schoenfeld, 2014). Westcott et al. (2001) recommended 2:1:4 as the best standard for tempo in resistance exercise repetitions. Here, 2:1:4 tempo defines a two-second concentric phase, a one-second isometric phase and a four-second eccentric phase.

Furthermore, although resistance training volume is often thought of in terms of sets, repetitions and total work, a concept called time under tension (TUT) can also be considered as a relevant variable. TUT can be defined as the total time a muscle or muscle group is subjected to mechanical stress during resistance exercise. In addition, it should be noted that there is no uniform terminology to describe the tempo of resistance exercise. Since there is no uniform terminology defining the value of tempo of movement in our study, we used the following criteria (Table 1.). This confusion in terminology provides a limitation for the evaluation of studies. The tempos mentioned above can be manipulated voluntarily in studies. Here, fatigue after exercise intensity is two important factors. Exercise at higher intensities lasts longer; concentric movement is slower at these loads. According to the force-velocity relationship, maximal strength production decreases as contraction velocity increases (Rogatzki et al., 2014). Therefore, lifters performing a fast movement experience a higher percentage of their maximum strength capacity to produce a given strength. Therefore, it can be predicted that training at a higher speed may reduce the number of repetitions that can be performed with a given weight. The decrease in power output with the onset of fatigue leads to a decrease in speed. A study by Mookerjee and Ratamess (1999) shows that partial range of motion in bench press exercise significantly increases bench press performance in both 1 RM and 5 RM conditions. For 1RM full range of motion, joint movement times during the flexion phase are significantly shorter than during the extension phase. For 5 RM, flexion times were significantly increased during both full and partial range of motion. Exercises performed at high intensities allow the concentric lift to change its tempo. Considering that eccentric strength is greater than concentric strength (Armstrong et al., 2022), different movement tempos and the contraction phases used in these movement tempos may produce differences in muscular performance with the training intensity variable.So far, there are review and meta-analysis studies evaluating muscular performances (hypertrophy, maximal strength, power) with research on movement tempos (Schoenfeld et al., 2015; Davies et al, 2017; Hackett et al., 2018; Wilk et al., 2021; Moreno-Villanueva et al., 2022). However, these studies did not present a holistic perspective as in our study. In addition, muscular endurance, which is an important muscular performance ability, was never evaluated in any of these studies. Furthermore, the effect of movement tempo on maximal strength, power, hypertrophy and muscular endurance at each stage of muscle movement is still not understood. Therefore, the aim of this review was to identify articles evaluating different contraction phases and tempo of movement during resistance training programs and analyze how tempo of movement influences strength, power, muscle hypertrophy and muscular endurance adaptations.

Table 1. Movement tempo classification.

Four-digit movement tempo variable	Example: 2:0:1:0
Three-digit movement tempo variable	Example: 2:1:2
Self-selected movement tempo variable	Example: SS:0:SS:0
Explosive strength movement tempo variable	Example: X:0:X:0
Isokinetic dynomometer tempo variable	Example: 30°/s or 180°/s

MATERIALS AND METHODS

Database Search

A literature search was conducted from 20/11/2022 with the last search being performed on 15/05/2023 with the years of research obtained from 1950-2023. Google Scholar, PubMed, Scopus databases were searched for all studies investigating the movement tempo. The research was performed using the following keyword combinations: (‘repetition duration or ‘tempo of movement ‘or ‘velocity of movement’) and (‘hypertrophy’ or ‘muscle mass’ or ‘strength’ or ‘muscle endurance‘or ‘muscle power’ resistance exercise’ or ‘performance’).

Inclusion and Exclusion Criteria

The literature search was conducted in November 2022 and included articles that were published from 1980 to May 2023. Study abstracts that did not provide sufficient information according to the inclusion criteria were retrieved for full-text evaluation This narrative literature rewiev were conducted in accordance with the recommendations outlined in the Preferred Reporting Items for Systematic Reviews (PRISMA) statement (Moher, Liberati, Tetzlaff, & Altman, 2009).

In addition to this the studies must further have completed the inclusion criteria seen in Table 2.

Table 2: Study eligibility criteria.

1	Study published within the years of 1980–2023.
2	English language.
3	Study was conducted on both male and female participants.
4	Participants must have been healthy and have no injuries, disability, or illness.
5	Adult participants (≥18 years of age)
6	Analysed the chronic training effects (4≥ weeks).
7	Dynamic resistance training intervention
8	Studies must have completed research via a comparative measure.
9	Measured changes in muscular hypertrophy using some direct and indirect measures (e.g. MRI, ultrasound, muscle biopsy, DXA and air displacement plethysmography)

Quality analysis

Methodological quality of studies meeting the inclusionary criteria was assessed using a modified Downs and Black quality assessment tool (Downs & Black, 1998). Scores range from 0 to 29 points, with higher scores reflecting higher-quality research.

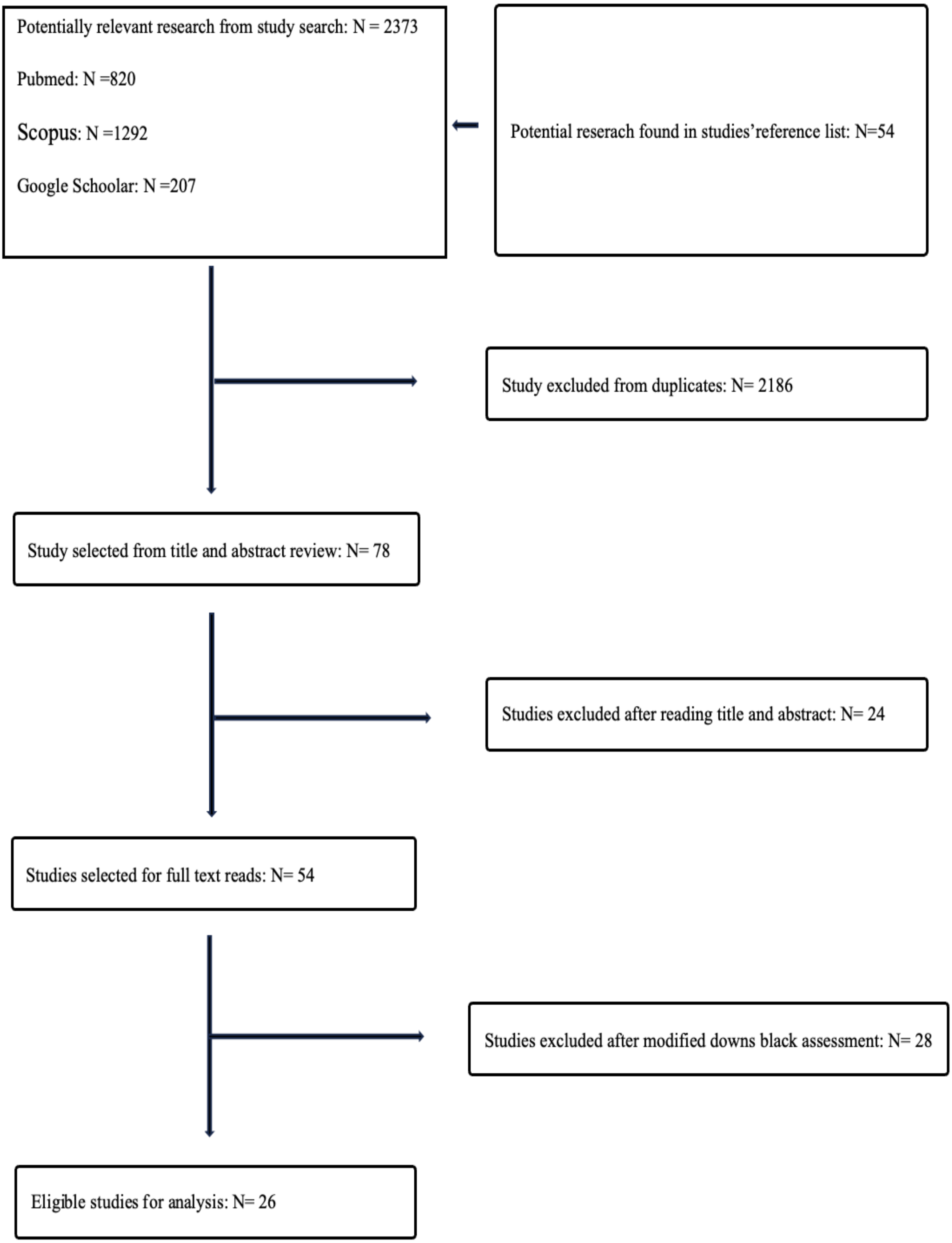

Figure 1: Study eligibility criteria.

RESULTS

Table 4 Experimental details of the studies in muscle hypertrophy with muscular fitness (Maximal Strength, Muscle Endurance and Power)

Study	Subjects	Age (year) ± (SD	Protocols	Duration weeks	Frequency days/week	Measurement	Main Findings
Keeler et al. (2001)	14 healthy, sedentary women	32.2±9.4 33.4±8.5	Leg extension, leg curl, leg press, bench press, Rowing, anterior Lateral pull-down, Biceps Curl, Triceps Extension, 1 set × 8–12 repetitions 5/0/10/0 (50%1RM) 4/0/2/0 (80%1RM)	10	3	BodPod 1RM Test	No significant differences in body composition, both groups increased their strength significantly on all 8 exercises, 4/0/2/0 group increased significantly more than the 5/0/10/0 group on bench press, anterior lateral pull-down, leg press, leg extension and leg curl.
Neils et al.(2005)	16 healthy untrained men and women	23.2 ± 2.9 21.4 ±1.5	Squat, Leg Extansion,Leg curl, Upright row, Bench Press, Biceps Curl, Triceps Extansion 1 set × 6–8 repetitions 5/0/10/0 (50%1RM) 4/0/2/0 (80%1RM)	8	3	DXA 1RM Test Force Plate (CMJ and SJ)	No significant differences in body composition. The 4/0/2/0 and 5/0/10/0 groups improved in strength the squat bench press, respectively. Peak power for the CMJ increased signifiantly in the TS group, no such increase was seen with respect to the 5/0/10/0 group. Both groups' 1RM increased significantl for both the bench press and the squat.
Rana et al.(2008)	34 untrained young females	20.6± 1.9 19.4 ± 1.3 22.3 ± 3.9 22.9 ± 2.4 C	Leg Press, Back Squat, And Knee Extension 3 set × 6-10 RM 4/0/10/0 3 set × 6-10 RM 2/0/1/0 3 set × 20-30 RM 2/0/1/0	6	3	BodPod 1RM Test Vertec device (VJ) 60% of 1 RM Test	Body composition improved for all groups including C (significant main effect). 4/0/10/0 increased relative leg press and knee extension 1 RM, but the percent increase was smaller than 2/0/1/0 (6-10 rep), and not different from C in the back squat. For muscular endurance, 4/0/10/0 improved similarly to 2/0/1/0 (20-30 rep) for leg press and less than 2/0/1/0 (6-10 rep) and 2/0/1/0 (20-30 rep) for knee extansion.
Schuenke et al.(2012)	34 untrained young women	20.6 ± 1.9 22.3 ± 3.9 19.4 ± 1.3 22.9 ± 2.4 C	Squat, leg press, leg extension 3 sets ×6-10 repetitions 2/0/1/0 (80 85%1RM) 4/0/10/0 (40–60%1RM) 3 sets ×20-30 repetitions 2/0/1/0 (80 85%1RM)	6	3	Biopsy 1RM Test	The percentage of type IIX fibers decreased and IIAX increased in all three training groups. Only 2/0/1/0 (6-10 rep) showed an increase in percentage of typeIIA fibers. CSA of fiber types I, IIA, and IIX increased in 2/0/1/0 (6-10 rep). In 4/0/10/0, only the CSA of IIA and IIX fibers increased.

Tanimoto and Ishii (2006)	24 untrained young men	19.0±0.6 19.5±0.5 19.8±0.7	Knee Extension 3 set × Max repetitions 1/1/1/0 (50%1RM) 1/1/1/0 (80%1RM) 3/1/3/0 (50%1RM)	12	2	MRI Isometric Strength Test	3/1/3/0 and 1/1/1/0 (80%1RM), exercise training caused significant increases in cross sectional area determined with MRI and isometric strength of the knee extensors, whereas no significant changes were seen in 1/1/1/0 (50%1RM).
Watanabe et al. (2013)	35 untrained men	66.8 ± 3.8 66.8 ± 5.2	Knee Extension and Knee Flexion 3 sets × 8 repetitions 1/1/1/0 (80–90%1RM) 3/1/3/0 (55–60%1RM)	13	2	Ultrasound Isokinetic Strength Test	3/1/3/3/0 significantly increased thigh muscle thickness as well as isometric knee extension and flexion strength. 1/1/1/1/0 significantly increased strength, but its hypertrophic effect was limited.
Pereira et al. (2016)	12 healthy adults	28.3 ± 8.2 30.3 ± 5.6	Scott curl 3 sets × 8 repetitions less than 8 reps or more than 8 reps, the weight load was adjusted (1/0/1/0) (1/0/4/0)	12	2	Ultrasound 1RM Test	No significantly differences were found between groups for hypertrophy and muscular strength.
Gillies et al. (2006)	28 female aduts RT experince	24.3 ±1.1	Bilateral Incline Leg Press, Parallel Squat, Bilateral Leg Extension and Leg Extenion (2/0/6/0) 3 sets × 6-8 RM (6/0/2/0) 3 sets × 6-8 RM	9	3	Biopsy 1RM Test	Both groups experienced significant increases in leg press maximal strength. Immunohistochemical analyses demonstrated that both types I and IIA vastus lateralis fibre areas Significantly increased following (2/0/6/0) training while only type I fibre area increased following (6/0/2/0) training.
Diniz et al. (2022)	44 untrained women	25.3±34.1 C 20.8±2.0 21.3±3.5 21.3±1.9	Knee Extension 3–5 sets × 6 repetitions at 50% 1RM (5/0/1/0) (3/0/3/0) (1/0/5/0)	10	3	MRI	The change in CSA of the rectus femoris at the middle region are greater in (5/0/1/0) and (1/0/5/0) groups than (3/0/3/0) and control groups. In addition, vastus lateralis at the distal region presenting greater increases in change of CSA than the others vastus only (5/0/1/0).
Azevedo et al. (2022)	Ten healthy young adults (8 men, 2 women)	25.3±4.8	Unilateral Knee Extension 5 sets 70% of 1RM until muscle failure (2/0/1/0) (4/0/1/0)	8	2	Ultrasound	Both a 2 second and 4 second eccentric duration promote similar improvements in whole muscle hypertrophy and strength of the lower limbs.
Chavez et al. (2020)	20 healthy untrained men	24.7 ± 2.9	Leg Extension 3 sets 70% of 1RM until muscle failure (2/0/2/0) (SS/0/SS/0) (volum equal) (SS/0/SS/0) (volum not equal)	8	2	Ultrasound 1RM test	All training protocols showed significant increases in values of 1-RM from Pre to Post. No significant main effect of group or groups vs. time interaction were found. Vastus lateralis muscle CSA values increased for all training protocols from Pre to Post. No significant main effect of group or groups vs. time interaction were found.

Unlu et al.(2020)	41 young, healthy males	20.5±1.9 20.1±1.4 21.6±0.5 22.4±1.5 20.9±2.3 21.3±2.4 C	Knee Extension 3–5 sets × 6-10 repetitions at 115-50% 1RM HV 180°/s - LV 30°/s – CO/EC 180°/s	12	3	MRI Isokinetic Strength Test	Significant increases compared with the control group were found for muscle isotonic strength and isokinetic peak torque at 60°/s in all training groups after the 12 weeks of the training period. There was no statistically significant interaction between groups and time on muscle volume.
Usui et al.(2015)	16 healthy young men	22.2 ± 2.1 22.5 ± 0.5	Parallel Squat 3 sets × 10 repetitions at 50% 1RM (exercise load adjusted every week) (1/0/1/1) (3/0/3/0)	8	3	Ultrasound 1RM test Custom-made lifting power test Isokinetic Strength Test	The (3/0/3/0) group significantly (increased muscle thickness (6–10 %), isometric hip extension torque (18 %) and 1-RM squat(10 %), but not isometric knee extension torque,lifting power, leg extension power and vertical jump height.
Carlson et al. (2019)	59 male and female aduts RT experince	39 ±14 39 ±10 42 ±14	Two workouts were performed (A & B, all muscle group) (4/0/2/0) 8-12 RM (10/0/10/0) 3-5 RM (30s CO/30sEC/30sCO) 1-5 RM	10	2	BodPod 1RM test	Analyses revealed significant increases in strength for all exercises but no between group differences, and no statistically significant time course changes for the other variables.
Fisher et al. (2016)	59 male and female aduts RT experince	39 ±1.2 40 ±1.1 39 ±1.4	Leg Press, Leg Extension, Leg Curl, Chest Press, Pec Fly, Over Head Press,Pull Over (1 traditional (4/0/2/0) and 1 eccentric (10/0/0/0+%30 load) each week) 8-12 RM (10/0/2/0) 6 RM (4/0/2/0) 8-12 RM	10	2	BodPod 1RM test Muscular performance test	No significant between groups differences were identified for change in muscular performance measures for leg press or chest press exercises, or for body composition changes. Significantly greater improvement for (4/0/2/0) compared to other groups for change in absolute muscular endurance for the pull-down exercise. Effect sizes for muscular performance changes were moderate to large for all groups and exercises.
Claflin et al. (2011)	63 young and old untrained men and women	24.2± 2.3 76.0 ±3.8, 24.9± 2.7 75.2± 4.3	Leg Press 350 and 250°/s 90 and 30°/s, Knee Extension 160 100°/s, and 40 and 20°/s	14	3	Biopsy	Both types of RT 8-12 % increase in type II fibers, No effect of training on type I fibers
Nogueira et al. (2009)	24 older male	66.64 ± 5.68 66.33 ± 4.53	Leg Press, Knee Extension, Knee Flexion, Chest Press, Seated Row, Elbow Extension, And Elbow Flexion 3 sets × 8 repetitions 3/0/1/0 (40,50 and 60%1RM) 3/0/3/0 (40, 50 and 60%1RM)	10	2	Ultrasound 1RM test Peak muscular power test	Training-induced gains in strength were similar between groups, however 3/0/1/0 induced significantly greater development in muscle power. There were significant increases in rectus femoris muscle thickness for 3/0/1/0 but not for 3/0/3/0. There were not significant differences in the post training values of muscle thickness between groups. Biceps brachii muscle thickness significantly increased for both 3/0/1/0 and 3/0/3/0.

SD standart deviation, CSA cross-sectional area, °/s degrees per second, DXA dual x-ray absorptiometry, FFM fat-free mass, MRI magnetic resonance imaging, RM repetition maximum, RT resistance training, C Control, RM repetition maximal, CO concentric, EC eccentric, HV high velocity, LV low velocity, CMJ counter movement jump, VJ vertical jump, SJ squat jump

Table 5 Experimental details of the studies muscular fitness (Maximal Strength, Muscle Endurance and Power)

Study	Subjects	Age (year) ± *(SD)/ Group*	Protocols	Duration weeks	Frequency days/week	Measurement	Main Findings
Gois et al. (2014)	105 healthy men	22±3 C 20±3 21±2.5	Knee Extensions 3 set × 1-8 repetitions (1/0/3/0) 80-100 % 1 RM (3/0/1/0) 80-100 % 1 RM	4	3	1RM test	The 1 TM test revealed an increase in muscle strength at the final timepoint in relation to the baseline for the (3/0/1/0) group.
Liow and Hopkins (2003)	27 male and 11 female sprint kayakers	22.0 ± 4.0 C 23.0 ± 5 23.0 ± 6	Bench Press and Dumbell Rowing 3 sets to failure at 80% 1 RM Both groups (~1.7 s for the eccentric phase). LV (~1.7 s for the concentric phase). HV "explosively, as fast as possible" (in 0.86 s)	6	2	1RM Test Kayak sprint test	Relative to control, both types of weight training substantially improved strength and sprint performance. The improvements in mean sprint time over 15 m in each group.
Morrissey et al.(1998)	21 healthy college-age female	24.0 ± 3.0 24.0 ± 4.0	Barbell squat 3 sets × 8 repetitions 1/0/1/0 (8 RM) 2/0/2/0 (8 RM)	7	3	Isokinetic Strength Test Long jump tests	In the long jump, 1/0/1/0 was superior in numerous variables including knee peak velocity and total body vertical and absolute power. In isokinetic testing, 1/0/1/0 improved strength most at the faster velocities, while the 2/0/2/0 strength changes were consistent across the velocities tested.
Munn et al. (2005)	115 untrained healthy subjects (21 males and 94 females)	20.6 ±6.1	Elbow Flexion 1-3 set to failure at 6–8 RM 1/0/1/0 (8 RM) 1 Set 3/0/1/0 (8 RM) 3 Set 1/0/1/0 (8 RM) 3 Set 3/0/1/0 (8 RM) 1 Set	7	3	1RM Test	1 set 3/0/1/0 increased strength by 25% . Three sets of training produced greater increases in strength than one set and fast training resulted in a greater increase in strength than slow training. The interaction between sets and speed was negative and of borderline significance.
Pareja-Blanco et al. (2014)	21 untrained men	23.3 ± 3.2 23.3 ± 3.2	Parallel Squat (isoinertial) 3–4 sets 2–8 repetitions at 60–80% 1 RM maximal intended concentric (0.49m/s) half-maximal intended concentric (0.82m/s) controlled eccentric (~0.50–0.65m/s)	6	3	20-m sprint Test Jump Test (CMJ) progressive isoinertial loading Test	Training resulted in a significant increase in 1RM squat strength and isoinertial strength for both groups. Greater intra-group effect size in all isoinertial strength variables were found for maximal intended CON velocity when compared to half- maximal CON velocity. A significant 'group'×'time' interaction was observed for CMJ height , whereas no significant interactions were found for T10 or T20.
Fielding et al. (2002)	30 untrained men	73.2 ± 1.2 72.1 ± 1.3	Knee extension, Leg Press 3 sets × 8 repetitions	16	3	1RM Test	Leg press and knee extansion relative training strength and total work were similar between groups. However, 2/1/X/0 generated significantly higher power during training sessions than 2/1/2/0 for leg press and knee extansion. Although leg press and knee

			2/1/X/0 (70%1RM) 2/1/2/0 (70%1RM)			Peak Muscle Power Test	extansion 1RM muscle strength increased similarly in both groups as a result of the training, leg press peak power increased significantly more in 2/1/X/0 than in 2/1/2/0 . Furthermore, 2/1/X/0 resulted in a significantly greater improvement in leg press power at 40%, 50%, 60%, 70%, 80%, and 90% of the 1RM than did 2/1/2/0.
Mike et al. (2017)	30 college-aged males	22 ± 2.1 22 ± 2.1 23 ± 4.2	Plate-Loaded Barbell Smith Squat (2/0/2/1) 4 sets × 3-6 RM (4/0/2/1) 4 sets × 3-6RM (6/0/2/1) 4 sets × 3-6RM	4	2	1RM Test Plyometric Platform Test	Significant group x time interaction effects were found for average power production across all three sets ofa squat jump protocol while vertical jump did not reach significance but there was a trend towards a difference. No other significant group x time interaction effects were found for the performance variables. All groups showed significant main effects for time in 1RM, vertical jump, peak power and average power.
Wei Lu et al.(2023)	17 healthy resistance-trained men	18.5 ± 0.5	Smith Machine Back Squat (2/0/2/0) 5 sets × 3 repetitions at 85 % 1RM (1/0/1/0) 5 sets × 3 repetitions at 85 % 1RM	8	3	1RM test Jump Test (CMJ)	Maximal strength, jump height, peak power and strength of the two groups were significantly improved. In addition, peak velocity significantly increased after the intervention in the (1/0/1/0) group, but not in the (2/0/2/0) group. A significant interaction effect between training groups was observed for jump height. However, no significant group by time interaction effects were found between training groups for maximal strength.
Bottaro et al.(2007)	24 inactive male subjects	66.6 ± 5.8 66.3 ± 4.8	Leg Press, Knee Extension, Knee Flexion, Chest Press, Seated Row, Elbow Extension, Elbow Flexion 3 sets × 8-10 repetitions X/0/X/0 (60%1RM) 2–3/0/2–3/0 (60%1RM)	10	2	1RM Test Isokinetic Strength Test	There was also ansignificantly greater improvement in muscular power in the X/0/X/0 group. There was no significant difference between groups in improved muscular strength.

SD standart deviation, CSA cross-sectional area, °/s degrees per second, DXA dual x-ray absorptiometry, FFM fat-free mass, MRI magnetic resonance imaging, RM repetition maximum, RT resistance training, C Control, RM repetition maximal, CO concentric, EC eccentric, HV high velocity, LV low velocity, CMJ counter movement jump, VJ vertical jump, SJ squat jump

DISCUSSION

Influence of Movement Tempo on Muscle Hypertrophy

Muscle hypertrophy, like many resistance training variables, can be influenced by manipulation of movement tempo, and research suggests that a wide range of movement tempos can be used during resistance training to elicit skeletal muscle growth (Schoenfeld et al., 2015; Davies et al., 2017; Wilk et al., 2021). The primary hypothesis in research on movement tempo for muscle hypertrophy is that intentionally extending the duration of repetitions leads to a superior hypertrophic response, and hypothetically, increased mechanical tension could promote a greater hypertrophic response by positively mediating intracellular anabolic signals (Schoenfeld, 2020). As we mentioned earlier, the concepts of movement tempo as a resistance exercise program variable are complex, as seen in research, but tempos that refer to eccentric, isometric, concentric, and isometric phases (e.g., 2/0/2/0), mostly consisting of four numbers, were generally used in research. In some studies, 3-digit numbers representing the sum of the concentric, eccentric and isometric components and angular velocities were specified as tempo in studies in which exercise was practiced with isokinetic dynometers. In addition, while some studies compared eccentric and concentric phases for slow, medium or fast tempos, some studies compared a single contraction phase over different tempos. Within these studies, different resistance exercise intensities were also applied for similar tempos.

Some of the studies comparing different movement tempos dealt with traditional tempos and slower tempos. In these studies, although the movement tempos were characterized as traditional, 4/0/2/0 (80%1RM) and 2/0/1/0 (80 85%1RM) tempos were used as traditional resistance exercise tempos. Schuenke et al (2012) found a significantly greater increase in total mean fiber CSA in the conventional and super slow training protocol. The training intensity of 4/0/10/0 and 40-60% 1RM for the super slow training protocol and 2/0/1/0 and 80-85% 1RM for the fast training protocol were determined and the training was performed for 3 sets of 6-10 repetitions until muscle exhaustion. The result of this study showed that strength training at slow speed elicited greater adaptation compared to training with similar resistance at "normal" speed, but training at higher intensity at "normal" speed resulted in the greatest overall muscle fiber response in each of the variables evaluated. In contrast, in another study using direct measurement by muscle biopsy, a similar level of hypertrophy response was obtained in both slow and fast tempo protocols (Claflin et al., 2011). In this study, the exercises were determined by means of an isokinetic dynomometer and the average repetition time was lower than in the study by Schuenke et al. In this case, it can be said that slow tempos have a limit in themselves. A follow-up study after this study found that satellite cell content was also significantly higher among fiber types after conventional training compared to super-slow training (Herman-Montemayor et al., 2015). In this study, the variable of voluntarily very slow movement tempo stimulated type IIx high-threshold fibers more. The results showed that although fatigue caused progressively greater recruitment of high-threshold motor units during light load training, the extent of high-threshold recruitment was greater during heavier loading. Although motor unit recruitment is necessary for muscle hypertrophy to occur, recruitment alone is not sufficient to promote hypertrophy; one of the most important factors is metabolic stress (Signorile et al., 2014; Tomeleri et al., 2020). Metabolic stress is the exercise-induced accumulation of metabolites, particularly lactate, inorganic phosphate and H+ (Schoenfeld, 2020). Some researchers have speculated that metabolite accumulation may have a greater effect on muscle hypertrophy than high-strain development (Ter Haar Romeny et al., 1982; Lacerda et al., 2016), but other researchers dispute this claim (Fonseca et al., 2014). In a study comparing energy expenditure and blood lactate responses to exercise at 2/0/2/0 (slow), 1/0/1/0 (recreational exercise) and 2/0/X/0 (fast) movement tempos in trained and untrained men, blood lactate concentrations continued to increase significantly at +90 and +120 minutes after 2/0/2/0 (slow) movement tempo in trained and untrained men compared to other groups (Mazzetti et al., 2007). Although the results of this study suggest that the slow movement tempo protocol induces more metabolic stress, it is insufficient to associate it with hypertrophy.

In addition, some studies dealing with traditional tempos and slower tempos do not reveal different results. Neils et al. (2005) compared a traditional training protocol of 4/0/2/0 movement tempo with 80% 1RM intensity with 5/0/10/0 50% 1RM. Keeler et al. used the same training protocols in their study, but no significant change in fat-free mass (FFM) was found in both studies. In another study in which FFM was measured, no significant difference was observed between 4/0/2/0 8-12 RM, 10/0/10/0 3-5 RM, 30s CO/30sEC/30sEC/30sCO 1-5 RM exercise protocols in terms of hypertrophy in the main effect (Carlson et al.,). Regarding FFM measurements, 3 months of resistance exercise training in adolescents resulted in a significant increase in appendicular skeletal muscle size when MRI was used as the measurement method, but there was no significant difference in fat-free mass by DXA (Lee and Kuk, 2013)20. Another study, this time in older adults, reported increases in thigh muscle size after a 1-year resistance training protocol measured by CT but not by DXA (Nelson et al., 1996). One study found that DXA was unable to accurately detect changes in lean mass in response to resistance exercise, strongly questioning the recent recommendation that it be considered the "reference standard" for muscle measurement (Tavoian et al., 2019). Another study by Rana et al. (2008) showed significant increases in FFM from baseline to post-study in all groups, including the control group, that underwent a 4/0/10/0 (6-10 RM), 2/0/1/0 (6-10 RM), 2/0/1/0 (20-30 RM) training protocol. It is interesting to note that the control group achieved similar FFM gains as the other groups despite not performing any exercise during the 6-week training protocols. Therefore, the results of these studies should be interpreted cautiously when trying to draw evidence-based conclusions about the hypertrophic effects of training speed.

A study on the effect of changes in movement tempo of eccentric and concentric phases on muscle hypertrophy compared training programs with light load (3/1/3/0; 50% 1RM), heavy load (1/1/1/0; 80% 1RM) and lighter load (1/1/1/0; 50% 1RM) (Tanimoto and Ishii, 2006). In the 12-week, two-day-a-week study, 3 sets of leg extension exercises were performed until muscle exhaustion. The 3/1/3/0; 50% 1RM tempo resulted in significantly greater hypertrophy in cross-sectional area (CSA) than the 1/1/1/0; 80% 1RM tempo. However, there was no difference in the hypertrophic response when the effect of training 1/1/1/0 with a lighter load (50% 1RM) was compared to 1/1/1/0; 50% 1RM tempo with a heavier load (80% 1RM). In another study with similar movement tempos other than isometric contraction tempo, healthy young men were assigned to 3/0/3/0 with 50% 1RM intensity for slow movement tempo and 1/0/1/0 with 50% 1RM intensity for normal movement tempo. Both groups underwent an 8-week squat training program (10 reps/set, 3 sets/day, and 3 days/week) using the assigned methods (Usui et al., 2015). The 3/0/3/0 group significantly increased muscle thickness (6-10%). Therefore, these studies suggest that slowing down the tempo for the goal of skeletal muscle hypertrophy may compensate for the reduction of the load used. In these studies, leg extension and squat exercises were used as a single exercise, but Tanimoto et al. (2008) compared fast (1/0/1/1; 80-90% 1RM) and slow (3/0/3/0; 55-60% 1RM) tempos in a whole-body resistance training program and showed that similar hypertrophic effects were observed in two different tempo and intensity protocols, consistent with these studies. Thus, from a practical point of view, it seems that a fairly wide range of repetition times can be used if the primary goal is to maximize muscle growth. The results suggest that voluntarily training at very slow times (10 seconds per repetition) is inferior in terms of hypertrophy. (2020), leg extension exercise (fast eccentric; fast-concentric; fast-concentric; slow-eccentric; slow-eccentric; slow-concentric; and concentric-eccentric, 30°-s for slow contractions and 180°-s for fast contractions) 3 days a week for 12 weeks were divided into 1 of 5 resistance training groups or a control group without training. There was no statistically significant interaction between group and time on muscle volume. In this study, the TUT for the fast movement tempo groups was 8-10 seconds, while the slow movement tempo groups had TUT times of 30-40 seconds. Voluntarily longer and slower tempos with longer TUT times require lower exercise intensity and consequently lighter loads. This may be interpreted as a result of decreased motor unit activation due to lighter loads, affecting the acquisition of muscle hypertrophy. However, although the TUT times are equal, the duration of the eccentric and concentric phases are also important here. There are two studies in which the movement tempos of the concentric and eccentric phases were alternated with the same TUT times. One study evaluated directly with muscle biopsy while the other study evaluated with MRI. Gillies et al. compared 6/0/2/0 with 2/0/6/0 at 3 sets of 6-8 RMs and muscle biopsy analysis showed that both type I and IIA vastus lateralis fiber areas increased significantly following slower concentric contraction, whereas only type I fiber area increased following slower eccentric contraction, but the differences between the groups were not significant. (2022) compared 3-5 sets × 6 repetitions at 50% 1RM 5/0/1/0, 1/0/5/0 and 3/0/3/0 movement tempos in knee extension exercise. According to the MRI results, the area of change in the CSA in the middle part of the rectus femoris was larger in the (5/0/1/0) and (1/0/5/0) groups than in the (3/0/3/0) and control groups.

In addition, the vastus lateralis distal region showed greater increases in CSA change than the others at movement tempo 5/0/1/0. Thus, although slow and fast tempos at different contraction types over 6-8 s TUT in the two studies elicited a muscle hypetrophy response, it is difficult to say whether it occurred as a result of changes in a combination of changes in both phases of movement. A meta-analysis by Schoenfeld and colleagues (2015) of randomized trials directly comparing training tempos in dynamic exercise using both concentric and eccentric repetitions shows little difference in muscle hypertrophy when training with isotonic repetition times ranging from 0.5 to 6 seconds until muscle failure. Therefore, he suggested that a fairly wide range of repetition times could be used if the primary goal is to maximize muscle growth. It has been stated that the limited research on this subject makes it difficult to draw concrete conclusions. In addition, training with very slow voluntary movement times of 10 seconds or more per repetition seems to cause lower increases in muscle growth, but again, the lack of studies on the subject makes it difficult to draw firm conclusions. In addition, some studies have compared eccentric and concentric phases within slow and fast tempos, and contradictory results have emerged. In one of the studies comparing different protocols in concentric phases, Nogueira and colleagues (2009) found greater increases in muscle thickness in the 3/0/1/0 movement tempo protocol with a 1-second concentric movement tempo compared to the 3/0/3/0 movement tempo protocol with a 3-second concentric movement tempo. Asis-Pereira et al. (2016) compared 1/0/1/0 and 1/0/4/0 with a similar protocol, although the movement tempos were different, and there was no significant result in terms of muscle hypertrophy between the two groups. Although 3x8 repetitions were performed in both studies, in the study of Nogueira and colleagues (2009), 1 RM 40-60% in both groups, and in the study of Asis-Pereira and colleagues (2016), the weight load was adjusted when less than 8 repetitions or more than 8 repetitions were performed. It should also be noted that the study by Nogueira and colleagues (2009) was conducted in elderly individuals. There are some limitations in adjusting the intensities in these two studies. More research is needed in this regard. Also, in a study conducted in elderly individuals, 3/1/3/0 significantly increased thigh muscle thickness, but 1/1/1/0 only had a limited hypertrophic effect (Watanabe et al., 2013). In the study by Azevedo and colleagues (2022), although skeletal muscle hypertrophy was observed in both groups, the mean increases were similar. Only the vastus medialis showed more growth than the slower eccentric duration. The use of air displacement plethysmograph and ultrasound to determine muscle hypertrophy in these two studies is a limitation in terms of comparing the results of the two studies. A systematic review by Moreno-Villanueva and colleagues (2022) suggested that muscle hypertrophy in both trained and untrained subjects can be improved by concentric total repetitions of less than 8 seconds. He noted that the tempo of each individual muscle movement to maximize hypertrophic training results is still not completely clear. Another review study by Wilk and colleagues (2021) specifically mentioned the inconsistency of results and emphasized the differences in study experimental designs in this regard.

The results presented in this review suggest that changing the tempo of movement during resistance training may have an effect on muscle hypertrophy, but the results are not conclusive. Differences in the size of the muscles studied, the structure of the training programs, and the standardization of the experimental approach and data collection tools used may partially explain the discrepancy in results between tempos in different contraction phases or in the same contraction phases.

Influence of Movement Tempo on Maximal Strength

Maximal strength refers to the highest force that the neuromuscular system can produce during maximal voluntary contraction. Maximum strength is indicated by the highest load that an individual can lift at one time (Bompa and Haff, 2009). It is important for both athletes and individuals exercising for health. Like muscle hypertrophy, maximal strength, like many resistance training variables, can be affected by manipulation of movement tempo. A meta-analysis by Davies and colleagues (2017) shows that regardless of age and training status, similar increases in dynamic muscle strength can occur when all intensities are combined, using either fast or moderate-slow movement speed. However, when moderate intensities were used, there was a trend towards increased strength gains when faster movement speeds were used. However, there are limitations in this study such as acute training variables such as intensity and movement speed differed between each study, the training status of the participants varied significantly, some studies included older participants with little training experience, and differences in data collection tools. In addition, due to differences in the duration of the eccentric and concentric phases evaluated, the effects of movement tempo on strength may not provide precise information about the effect of specific phases of movement (eccentric or concentric) on strength gains. Furthermore, this study compared fast or explosive movements with slower ones and did not allow comparing extremely slow tempos between concentric or eccentric phases of movement. Therefore, the evidence is still inconclusive on how changing movement tempo will affect muscle adaptations in resistance-trained individuals.

Studies comparing different movement tempos for maximal strength have generally compared traditional tempos (1/0/1/0, 1/1/1/0, 1/1/1/0, etc.) and 2-3 second protocols in eccentric and concentric phases (Morrissey et al., 1998; Munn et al., 2005; Tanimoto and Ishi, 2006; Watanabe et al., 2013; Pereira et al., 2016; Usui et al., 2016). Among these studies, there is only one study in elderly individuals, while there is only one study comparing eccentric contraction tempos. In the study by Watanabe and colleagues, 3/1/3/0 (55-60% 1RM) significantly increased isometric knee extension and flexion strength in elderly individuals. 1/1/1/1/0 (80-90% 1RM) significantly improved strength. It should be noted that this study was performed in elderly individuals. ACSM recommends the use of slow to moderate speed and 60-80% of 1RM for strength increases in older adults (Chodzko-Zajko and American College of Sports Medicine, 2013). A meta-analysis (Borde et al., 2015) more specifically recommended 70-80% of 1RM and a slow duration under tension of 6 seconds per repetition, but this analysis did not consider movement tempo. However, studies comparing the effects of slow speed and moderate load versus fast speed and light to moderate load suggest that this is not the only way to increase maximal strength in the elderly (da Rosa Orssatto et al., 2019). Fast contractions at higher intensities appear to provide greater increases in strength compared to lower intensities (Byrne et al., 2016).

Unlike other studies, Pereira et al. (2016) evaluated the effect of changes in the eccentric phase of movement on strength gains during resistance exercise and compared slower eccentric movement tempo 4/0/1/0 with faster eccentric movement tempo 1/0/1/0 protocols and confirmed that the 4/0/1/0 group had an improvement in muscle strength between pre and post training. The 4/0/1/0 group had larger effect sizes in terms of strength from pre to post training than the 1/0/1/0 group. 4/0/1/0 training is more effective in increasing muscle strength in well-trained adults. As mentioned before, the time under tension during the eccentric phase of the movement increases metabolic stress and hormonal responses. This may affect both muscle hypertrophy and indirectly strength gains.

Although both slow (1/0/1/0 - 8 RM) and fast (2/0/2/0 - 8 RM) training protocols improved strength performance in isokinetic strength testing in the study by Morrisey et al. (1998), fast training may be superior to the slower speed used in this study in the magnitude of training effects. A study by Munn et al. (2005) showed that strength gains were greater with 1/0/1/0 tempo compared to 2/0/2/0. In the study by Usui and colleagues (2016), the 1/0/1/1 50% 1RM group did not show any change in all variables. The 3/0/3/0/3/0 50% 1RM group significantly increased isometric hip extension torque (18%) and 1-RM squat (10%), but not isometric knee extension torque. In Tanimoto and Ische's (2006) study, 3/1/3/0 (50% 1RM) and 1/1/1/0 (80% 1RM) exercise training caused significant increases in the isometric strength (maximal voluntary contraction) of the knee extensors, whereas 1/1/1/0 (50% 1RM) showed no significant change. In another recent study, Lu et al. (2023) compared 2/0/2/0 and 1/0/1/0 movement tempos and found that maximal strength improved significantly in both groups. However, no significant group and time interaction effect was found between training groups for maximal strength. Isokinetic strength was measured in four of these eight studies, while three studies used 1 RM test and one study used both. Training frequency was more than 7 weeks in all studies in terms of durations and only one study applied training frequency two days a week and the other studies applied training three days a week. As mentioned before, one study compared eccentric phases in elderly individuals and one study compared plain eccentric phases. Considering these limitations, it can be said that no significant difference was observed in terms of maximal strength in these studies comparing traditional tempos (1/0/1/0, 1/1/1/0, 1/1/1/0, etc.) and 2-3 second protocols in eccentric and concentric phases. Similarly, in a study conducted in elderly individuals, maximum speed tempos with X/0/X/0 in eccentric and concentric phases were compared with 2 or 3 second tempos. No significant difference was found between the groups in terms of improvement in muscle strength (Bottaro et al., 2007).

Some studies on strength and movement tempo have investigated the effects of much slower eccentric and concentric movement tempos. Keeler et al (2001) compared a 4/0/2/0 tempo of 80% 1RM intensity with 5/0/10/0 50% 1RM training protocols. They showed that 4/0/2/0 tempo was more effective in increasing strength compared to 5/0/10/0. However, greater strength gains were not observed in every exercise for 5/0/10/0 compared to 4/0/2/0 movement tempo in the study of Neils et al. (2005) who applied the same protocol. The only difference in these two protocols was the number of repetitions. In addition, Keeler et al. (2001) included individuals with no experience and Neils et al. (2005) included individuals with resistance exercise experience. These differences may be the reason for the differences between the study results. However, although the protocols used were different, Schuenke et al. (2012) used 4/0/10/0 and 40-60% 1RM exercise intensity for the super slow training protocol, 2/0/1/0 movement tempo with 80-85% 1RM intensity for 3 sets of 6-10 repetitions and 2/0/1/0 movement tempo with 80-85% 1RM intensity for 3 sets of 20-30 repetitions until muscle exhaustion for the fast training protocol. As in other studies, no significant difference was observed in strength gain. Another study by Rana et al. (2008) compared 4/0/10/0 (6-10 RM), 2/0/1/0 (6-10 RM), 2/0/1/0 (20-30 RM) training protocols and found that 4/0/10/0 increased relative leg press and knee extension by 1 RM, but the percentage increase was smaller than 2/0/1/0 (6-10 repetitions) and not different from the back squat control group. In another study, Carlson et al. (2019) compared super slow (10/0/10/0), medium (4/0/2/0), and very fast (30sc/30sc/30sc) protocols and analysis revealed significant increases in strength for all exercises but no differences between groups. Repetition time did not affect the increase in strength in trained participants where the exercise was performed to immediate failure.

The inconsistencies in these results may be related to the fact that the training protocols used in the studies used both concentric and eccentric phases as variables. Although there is a difference in the comparisons in these studies, it is difficult to explain which phase this difference is related to. For this reason, there are studies that only reveal variable protocols in concentric or eccentric phases. For example, Mike et al. (2017) compared eccentric movement tempos of 2, 3 and 4 seconds and found no difference in maximal dynamic power in resistance-trained subjects. However, Pereira et al. (2016) suggested that based on effect size, a slow eccentric phase may be better for increasing strength gains in trained individuals. Fisher et al. (2016) compared eccentric movement tempos of 4 and 10 seconds and found no significant difference in measures of muscular performance. It should be noted that in these studies, there were differences in exercise type and eccentric tempo choices, such as population, compound and single-joint, and training intensity was rarely equalized between groups. Apart from the studies comparing eccentric contraction phases, two studies comparing concentric phases showed different results. In the study conducted by Nogueira et al. (2009), strength gains measured with leg press and chest press were similar in 3/0/1/0 and 3/0/3/0 movement tempo. In a study that showed similar results to this study, although the protocols were different, both groups were exercised explosively as fast as possible (at 0.86 s) at a tempo of ~1.7 s and slow tempo for the eccentric phase and ~1.7 s and fast tempo for the concentric phase. Compared to the control group, strength performance improved to a similar degree in the fast and slow concentric protocol (Liow and Hopkins, 2003).

Power performance was also evaluated in this study, but we will discuss this result in the next section. Fielding et al. (2002) compared 2/1/X/0 and 2/1/2/0 movement tempo and found that 2/1/X/0 movement tempo improved 1RM power. Again, it should be noted that while the sample groups in these studies were similar in terms of consisting of elderly individuals, there was a slight difference in the duration of the concentric phases, which may explain the differences in strength gains. In addition, there are studies comparing eccentric and concentric phases at moderate or high speeds in movement tempo protocols that are equal in terms of tension under the same time. In these studies, Gois et al. (2014) compared 1/0/3/0 with 3/0/1/0 and Gilles et al. (2006) compared 2/0/6/0 with 6/0/2/0. The 3/0/1/0 group showed an increase in muscle strength at the end of the study. The 3/0/1/0 group showed an increase in muscle strength at the end of the study. Gilles et al. (2006) showed that both groups experienced a similar increase in maximal leg press strength with training in all strength assessments. The increase in eccentric strength was greater than the increase in combined or concentric strength for both groups. The fact that the duration of the eccentric and concentric phases were twice as different in these two studies, as well as the fact that Gois et al. (2014) used a single exercise protocol while the other study used a program consisting of multiple exercises is an important factor.

Unlike the other studies, as a result of a study comparing the self-selected movement tempo of the individuals participating in the study with the traditional movement tempo, all training protocols showed significant increases in 1-RM values. There was no significant main effect of groups and time interaction. Resistance training with self-selected repetition time, with or without volume loading, was equally effective in increasing muscle strength in untrained men compared to the conventional protocol. In this study, the time under tension for the traditional protocol was 4□0 seconds, the self-selected repetition time was 1.8□0.3 seconds and finally 1.7□0.4 seconds in the self-selected equalized volume load group. In this study, 2/0/2/0 tempo was selected for the traditional tempo and the fact that the averages of the self-performed tempos were close to this tempo may indicate the situation in the research results. Finally, Ünlü et al. (2020), in their study in which they performed knee extension exercises separately in eccentric and concentric phases at slow and fast tempos using a computer-based visual animation, found significant increases in muscle isotonic strength and isokinetic peak torque at 60°/s for all training groups after a 12-week training period compared to concentric+eccentric. There was no statistically significant interaction between group and time on isokinetic peak torque at 180°/s. The results of this study suggest that all training methods have the potential to cause isotonic power gains in the knee extensors and that there is insufficient evidence for the superiority of any particular muscle contraction or speed mode. From the literature, the available information does not indicate which eccentric and concentric repetition tempos are optimal for maximal strength development. However, a systematic review study by Moreno-Villanueva and colleagues (2022) showed that resistance training protocols with moderate eccentric muscle movement duration and fast concentric muscle movement duration, especially 4/0/1/0 tempos, produced the highest development values for maximal dynamic strength development in both trained (18-24%) and untrained subjects (10-14%). For maximal strength development, a medium total repetition muscle movement time of less than 4 seconds and a slow total repetition muscle movement time of less than 8 seconds seem to be appropriate for untrained and trained subjects, respectively, provided that the concentric muscle movement time is explosive or fast (cadence 4-8/0/max-3/0). In conclusion, the prescription of muscle movement time, total and phase-specific, should be planned according to the desired adaptations in untrained and trained subjects.

Influence of Movement Tempo on Muscle Power and Endurance

Power is the ability to generate strength rapidly. While power is important for athletes in most sports, it is not a muscular performance ability directly related to health for sedentary individuals, but it is an ability that may be needed for daily life activities (Bompa and Haff, 2009). Like power performance, muscular endurance is important for both athletes and sedentary individuals. Muscular endurance is the ability of the neuromuscular system to repetitively generate strength over long periods of time. The total number of repetitions that can be lifted with a given load is an indicator of muscular endurance (Hoffman, 2014). Resistance exercises are used to improve both components of physical fitness, and the variability of movement tempos may show different responses in these abilities.

Power is based on the force-velocity relationship (Pozzo & Impellizzeri, 2022) and therefore a resistance exercise variable approach based on the performance of explosive efforts at lower intensities (50-80% of 1RM) makes sense. Studies comparing the effects of movement tempo on muscle hypertrophy and maximal strength abilities have also provided data on power ability. In studies comparing different eccentric and concentric phases, vertical jump and long jump tests were generally used. As mentioned above, we have previously stated that faster tempos are more logical to use in resistance exercises for power gain. Although studies show that faster tempos are slightly more effective in power gain than slower tempos, there are studies that show different results. The only one of these studies that showed a significant difference in the fast tempo group compared to the slow tempo group was Neils and colleagues' (2005) study in which peak power for CMJ increased significantly from 23.0 ± 5.5 W/kg to 25.0 ± 6.3 W/kg in the 4/0/2/0 group; no such increase was seen in the 5/0/10/0 group. The results of this study suggest that 4/0/2/0 is more effective than 5/0/10/0 in improving peak power. In the Morrisey et al. (1998) study, in the long jump, the 1/0/1/0 group was superior in several variables, including knee peak velocity and total body vertical and absolute power. In the vertical jump, 1/0/1/0 affected the ankle and hip more (i.e. average power), while 2/0/2/0 mostly affected the knee (average torque). Although both slow and fast training improved performance, fast training showed some advantages in terms of the amount and magnitude of training effects. In another study, similarly, jump height, peak power and strength of the fast and slow movement tempo groups improved significantly, although peak velocity increased significantly after the intervention in the 1/0/1/0 group, but not in the 2/0/2/0 group (Lu et al., 2023). For jump height, a significant interaction effect was observed between the training groups. Unlike these studies, Rana et al. (2008) found no significant difference for jump height or muscle power in the 4/0/10/0 (6-10 repetitions), 2/0/1/0 (20-30 repetitions) and 2/0/1/0 (6-10 repetitions) movement tempo groups. Again after Usui et al. (2015) intervention, the 1/0/1/0 group did not show any change in all variables. In the 3/0/3/0 group, there was no significant change in knee extension power and vertical jump height. These results suggest that 3/0/3/0 has little effect on power production during dynamic explosive movements. It should be noted that although some of these studies had sample groups with resistance exercise experience, many studies included inexperienced individuals. This may affect the results. In addition, as we mentioned before when evaluating muscle hypertrophy and maximal strength, the fact that exercise intensities were not equalized may have had an effect in this case.

There are only studies investigating the effects of different eccentric and concentric movement tempos in relation to power. (2014) investigated the effects of concentric phases at maximal velocity and half-maximal velocity on CMJ and 20 m sprint test performance in terms of power. Pareja et al. (2014) performed Parallel Squat (isoinertial) exercise 6 weeks three days a week in a protocol (3-4 sets 2-8 repetitions at 60-80% 1 RM maximal intended concentric - 0.49m/s, half-maximal intended concentric - 0.82m/s, controlled eccentric - 0.50-0.65m/s.). While a significant 'group'×'time' interaction was observed for CMJ height, no significant interaction was found for the 10 m sprint. The change in individual CMJ values from before to after showed that maximal concentric velocity training probably caused a better effect on CMJ height performance compared to semi-concentric velocity, while the beneficial effects of maximal concentric velocity training compared to semi-concentric velocity on 10 m sprint and especially 20 m sprint are not clear. Another study, again comparing different movement tempos in concentric phases, although with differences in execution protocols, showed similar results between groups in relative training power and total work for leg press and knee extension, although 2/1/X/0 produced significantly higher power than 2/1/2/0 for leg press and knee extension during training sessions. Leg press and knee extension 1RM muscle strength increased similarly in both groups at the end of training, although Leg press peak power increased significantly more in 2/1/X/0 compared to 2/1/2/0. Also, 2/1/X/0 significantly.

Leg press power improved more at 40%, 50%, 60%, 70%, 70%, 80% and 90% of 1RM than 2/1/2/0. The evaluation criteria and protocols are different in these two studies, but it can be said that fast concentric phases show better results in power and output. Another study investigating concentric

phases on power output compared two protocols, 3/0/1/0 (40, 50 and 60%1RM) and 3/0/3/0 (40, 50 and 60%1RM), and training-induced power gains were similar between the groups, but 3/0/1/0 resulted in a significantly greater improvement in muscle power (Nogueira et al., 2009). In these studies, concentric phases and exercise intensities also differed from each other, making it difficult to compare the results with each other. However, it can be said that faster concentric phases have a more favorable effect on power outputs.
In the only study investigating different eccentric phases on power output, Mike and colleagues (2017) compared three protocols on 2/0/2/1, 4/0/2/1, 6/0/2/1 (4 sets × 3-6RM). For all performance data, significant group x time interaction effects were found for mean power production in all three sets of the squat jump protocol. All groups showed significant main effects for vertical jump, peak power and average power. Peak velocity data showed that the 6/0/2/1 group experienced a significant decrease in peak velocity during the squat jump protocol as a result of the 4-week training program. In this respect, further research is needed to elucidate the effects of different eccentric movement tempos on power performance.

Studies investigating muscular endurance performance through movement tempos are also in the minority. Rana and colleagues (2008) also evaluated muscular endurance performance. For muscular endurance, 4/0/10/0 improved similarly to 2/0/1/0 (20-30 repetitions) for leg press, but less than 2/0/1/0 (6-10 repetitions) and 2/0/1/0 (20-30 repetitions) for knee extension. Muscular endurance improved with 4/0/10/0 training, but not above that shown by 2/0/1/0 (20-30 repetitions) or 2/0/1/0 (6-10 repetitions). In another study evaluating muscular endurance, analyses revealed a significantly greater improvement for conventional training compared to eccentric groups for the change in absolute muscular endurance for the pull-down exercise (Fisher et al., 2016). The conventional group performed the exercises at a movement tempo of 4/0/2/0 and the eccentric group A performed the exercises at a movement tempo of 10/0/2/0. Eccentric group B performed 1 x traditional tempo and 1 x eccentric tempo only exercises each week. These two studies showed contradictory results in terms of contraction phases. Age difference and experience difference in the sample groups are the most important differences of the two studies. In addition, differences in resistance exercise protocols and movement tempos may explain these contradictions.

Conclusions

The results presented in this review suggest that varying the tempo of movement during resistance training may have an effect on the level of maximal muscle strength, muscular power and muscular endurance along with muscle hypertrophy, but the results are not conclusive. Differences in the exercise prescriptions in the protocols applied in the studies and the experimental designs used are a factor in the discrepancies between the studies. As a result of this review, there are data indicating that movement tempo should be considered in resistance training programs to increase hypertrophy and maximal strength. It is not clear whether a particular tempo is more effective than another for increasing muscular strength and endurance. Faster movement tempos seem to be effective in relation to muscular strength, but more research is needed. In the light of the literature, longer-term longitudinal studies on movement tempo should be conducted in both athletes and sedentary individuals, and resistance exercise prescriptions should be prescribed in accordance with muscular adaptation in weekly frequencies. There is a need for studies to demonstrate the effects of concentric or eccentric phases at different tempos. This may provide us with more information about which phase of movement tempo is effective in muscular fitness performance.

Conflict of interest

There is no personal or financial conflict of interest within the scope of the study.

Author Contributions

Planned by the author: Study Design, Data Collection, Statistical Analysis, Data Interpretation, Manuscript Preparation, Literature Search. Author have read and agreed to the published version of the manuscript.

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