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The need for eccentric speed: A narrative review of the effects of accelerated eccentric actions during resistance-based training. A narrative review of accelerated eccentrics.

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Abstract

Eccentric training, as a method to enhance athletic performance, is a topic of increasing interest to both practitioners and researchers. However, there is limited data regarding the effects of performing eccentric actions of an exercise at increased velocities. This narrative review aimed to provide greater clarity for eccentric methods and classification with regard to temporal phases of exercises. To achieve the object of the review, key terms were searched using PubMed, SPORTDiscus and Google Scholar databases between March and April 2021 within the years of 1950-2021.Search terms included: ('fast eccentric'), ('fast velocity eccentric'), ('dynamic eccentric'), ('accentuated eccentric loading'), ('isokinetic eccentric'), analysing both the acute and chronic effects of accelerated eccentric training on human participants. Of the 26 studies which met inclusion criteria, it was identified that completing eccentric tempos of <2s can increase subsequent concentric one repetition maximum performance, velocity, and power, compared to >4s tempos. Durations of >4s tempo increase time under tension (TUT); whilst reduced tempos allow for greater volume to be completed. Greater TUT leads to larger accumulation of blood lactate, growth hormone and testosterone, when volume is matched to that of the reduced tempos. Overall, evidence supports <2s duration eccentric actions to improve subsequent concentric performance. There is no clear difference between using eccentric tempos of 2–6s if the aim is to increase hypertrophic response and strength. Future research should analyse performing eccentric actions at greater velocities or reduced time durations to determine more factors such as strength response. Tempo studies should aim to complete the same TUT for protocols to determine measures for hypertrophic response.

Key Points

The term of Accelerated Eccentrics should be reintroduced to define eccentric actions that are performed at increased velocities with the addition of specific verbal cues.

There is no clear difference between <2s versus >4s eccentric tempos and <60°s^{-1} versus >180°s^{-1} eccentric isokinetic dynamometry for increasing muscle mass in a longitudinal training programme.

There is a need for more academic research to view the effects of accelerated eccentrics to determine how it impacts both the acute and longitudinal response to training.

1.0 Introduction

Eccentric training as a method to enhance athletic performance is a topic constantly under review as researchers aim to understand the physical capabilities that these muscle actions can elicit. There is a gap in the knowledge base when comparing the eccentric to the concentric side of the force-velocity curve [1,2]. It is widely accepted that during multi- and single-joint actions, eccentric muscle lengthening forces can reach 100-150% of a concentric one repetition maximum (1RM) or 20-60% greater than concentric actions [3–8]. The emergence of this understanding has led academics and coaches to create, test, and implement training methods to incorporate this mode of training. Primarily, methods have concentrated on increasing the mass utilised to increase eccentric forces illustrated via supramaximal loads through methods such as accentuated eccentric loading (AEL) [9–11].

The training procedure of accelerated eccentrics is often overlooked despite regular discussion in the literature (Table 1) [5,12–17], this centres on increasing the acceleration (eccentric velocity) of any movement, though this is not fully investigated [18]. Eccentric force-velocity relationships differ to concentric muscle actions [18,19] first devised by Hill's muscle model [20]. During eccentric muscle lengthening, higher forces are attained alongside high velocity [13,14,16,20–28]. Though, this statement only holds true to a certain degree, for example, if tension (force and velocity) is too great then an individual would not be able to produce enough force to decelerate and would continue to displace through a motion [23,27,29]. The enhancement in force production is thought to be achieved by an increase in the proportion of cross bridges or an increase in the average force per cross bridge or both [22]. The giant protein Titin has also been theorised to play a role by storing elastic energy in the I-band region [3,12,22]. Evidence demonstrates that the key role for Titin in the lasting force enhancement during lengthening actions is down to increases in Titin stiffness termed “passive force enhancement” [30–33]. Therefore, it is now more prudent to understand that it is not only cross-bridges, but also Titin, that contribute to enhanced force levels during lengthening actions as Titin demonstrably enhances stiffness during all other phases of an eccentric contraction.

Biomechanically, utilising greater eccentric velocities may provide training performance enhancements. If the aim is to increase the acceleration of a known mass over a set range of a motion than a greater force is required to be able to accelerate a mass at a greater rate ($\boldsymbol{F}$ = m x $\boldsymbol{a}$). When observing kinetic energy (*ke* = m x $\boldsymbol{v}^2$), increasing the velocity has a greater effect on *ke* than enhancing mass [13,16,37]. This can be seen when employing drop and depth jumps (shock method) as the height of the platform is increased potential energy is augmented as there is a larger distance to accelerate through. In doing so this potential energy is transferred into *ke* once a person steps off a platform and begins to free fall [13,38,39]. This asserts that to increase the acceleration of a movement force must be enhanced or the duration at which force is applied can increase, therefore a coach can increase the aforementioned metrics without the need to increase the mass ensuring duration remains the same.

Momentum is defined as mass in motion and again can be enhanced by increasing velocity or mass. Therefore, if an object is travelling at a greater velocity then an increased force would be required to decelerate it [40]. This can also be altered by an individual performing voluntary actions such as pulling the barbell down to increase eccentric acceleration. Subsequently, some authors have investigated increasing eccentric velocity during resistance-based training, this method though is performed as an isoinertial action and will achieve a greater eccentric tension as the velocity of the action is increased. This method would apply a far simpler process than weight releasers [41–43] or specialized equipment [44] found during supramaximal loaded AEL studies. Subsequently, being more pragmatic for coaches to apply greater emphasis on increased eccentric velocity exercises, though there is little evidence to support this claim.

Eccentric training has been recognized as a valid training method for performance enhancement [14,43]; however, there is a distinct lack of consistency in the terms used to describe the duration and velocity of eccentric training in the research. Furthermore, there is limited research into the area of accelerated eccentric training, thus a review of the current topic is warranted. The aims of this narrative review is to firstly, examine the available literature pertaining to accelerated eccentric training and the application of this modality to provide a greater understanding of the adaptions that are evidenced to occur from accelerated eccentrics and secondly, to provide more consistent and accurate terminology for practitioners to use.

Table 1: Current review terms and definitions of said terms.

Term	Acronym	Definition
Accelerated Eccentric	NA	The training method whereby, the aim is to perform the eccentric phase at an increased velocity, determined by eccentric phase execution strategies.
Overspeed Eccentric	NA	The addition of resistance bands by causing the subject to move faster on the eccentric phase producing more power for reversal strength.
Accelerated Eccentric Loading	ACEL	The training method where resistance bands are employed to accelerate the eccentric phase of an exercise and the bands are then released prior to the concentric phase of an exercise.
Accentuated Eccentric Loading	AEL	The training method whereby the eccentric phase of an eccentric concentric coupling exercise has an increased mass than when compared to the concentric phase.
Isokinetic Dynamometry	IKD	The training method whereby, an isokinetic device is utilised to complete an exercise.
Tempo Training	NA	The training method whereby, an allotted time duration is given in respect to the eccentric, isometric, concentric and isometric phases of an exercise.
Fast tempo	NA	Term should be avoided, however, if used it defines a tempo that is faster than its counterpart.
Slow Tempo	NA	Term should be avoided, however, if used it defines a tempo that is slower than its counterpart.
Isoinertial	NA	When mass is consistent during resistance-based training.

NA: Not applicable.

2.0 Methods

2.1 Database Search

A literature search was conducted from 02/03/2021 with the last search being performed on 21/04/2021 with the years of research obtained from 1950-2021. Pubmed and SPORTDiscus search engines where utilised whereby title, abstract and key words where viewed. Google Scholar was searched using the advanced search section. Furthermore, reference lists from the identified studies via the database searchers were also examined to discover any additional research that could be used in the current review. The following search terms were included: (‘fast eccentric’), (‘eccentric velocity’), (‘dynamic eccentric’), (‘overspeed eccentric’), (‘accentuated eccentric loading’), (‘isokinetic eccentric’), (‘lengthening velocity’), (‘deceleration training’), (‘fast stretch shortening cycle’). The study analysed both the acute and chronic effects of accelerated eccentric training on human participants. Research studies that only utilised one eccentric aforementioned value (duration or velocity) would be utilised to justify results but not used in the analysis (Table 2).

2.2 Inclusion and Exclusion Criteria

Initially, after studies were collated if they did not complete the same Concentric methods they were excluded as this would not allow comparisons to be made across protocols. In addition to this the studies must further have completed the inclusion criteria seen in Table 2.

Table 2: Study eligibility criteria.

1.	Peer reviewed journal article displayed (full text).
2.	English language.
3.	Study published within the years of 1950–2021.
4.	Study was conducted on both male and female participants.
5.	Participants must have been healthy and have no injuries, disability, or illness.
6.	Participants were aged 18-50 years of age.
7.	Analysed the acute and/or chronic effects of eccentric training.
8.	Study must have viewed more than one eccentric: duration, speed, velocity, and torque values.
9.	Studies must have completed research via a comparative measure.
10.	Concentric performance if tested must have been the same across testing.

3.0 Results

3.1 Literature Search Results

Of the 987 studies found during the database sear h, 49 met the inclusion criteria, these were then further analysed via a modified Downs-Black assessment [88] (Figure 1). Two separate modified Downs-Black assessments were undertaken as the current review analysed both the acute and chronic effects of accelerated eccentric training. Two researchers conducted the modified Downs-Black assessments, if studies achieved a score of 10 and below during the modified Downs-Black assessment, they were removed from the analysis to better improve the current studies bias. After the modified Downs-Black analysis, 26 studies were selected for further review. Acute results of tempo studies and isokinetic dynamometer can be found in Table 3 and 4, respectively. The chronic effects of tempo and isokinetic dynamometry can be found in Table 5 and 6, respectively.

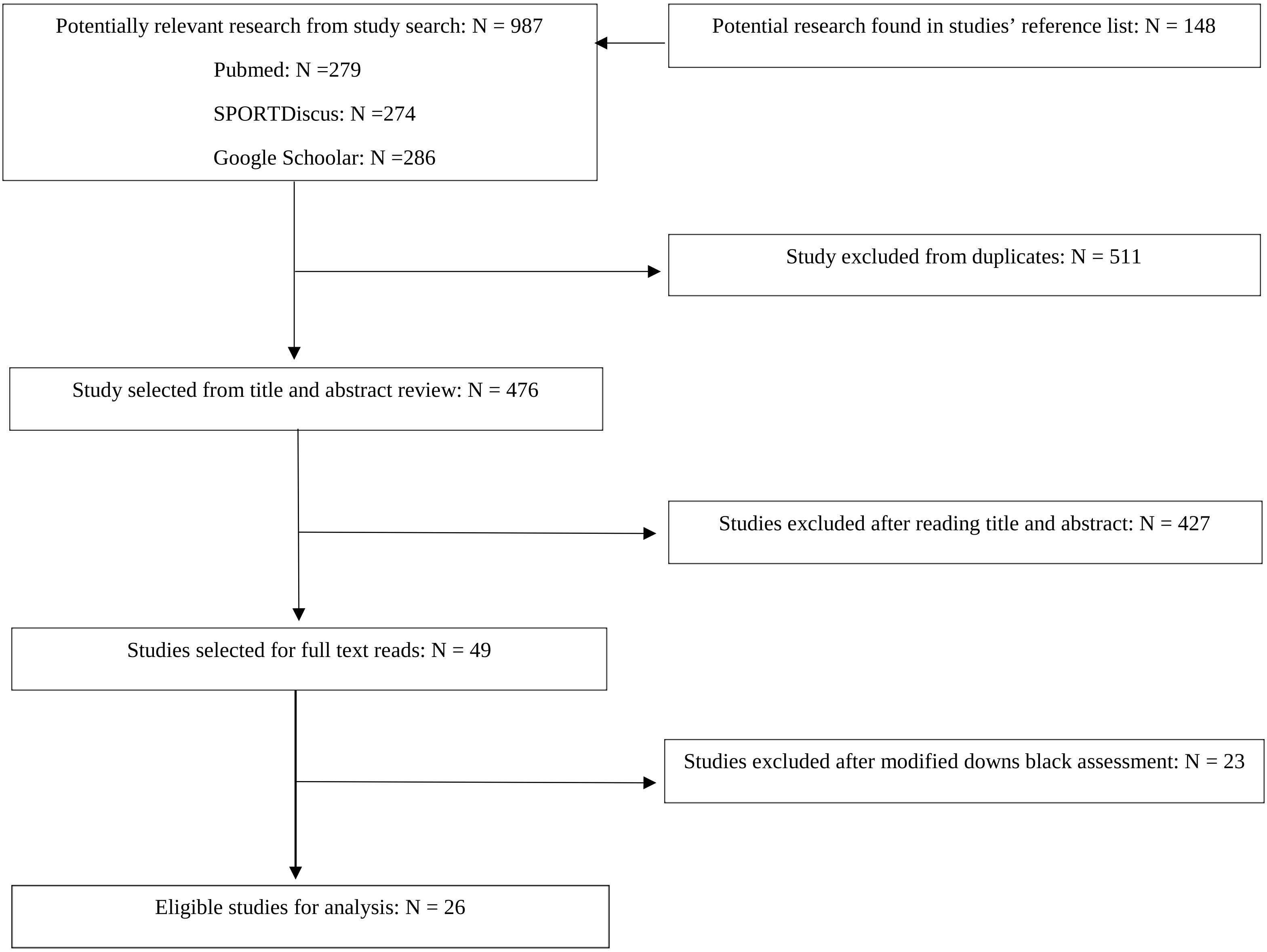

Figure 1: Schematic of search strategy process.

3.2: Tables of Findings

Table 3: Acute tempo studies.

Study	Population	Aim	Method	Findings
Van den Tillaar [81]	N = 11 healthy resistance trained males age = 24.0 ± 6.0 yrs, BM = 89.5 ± 21.5 kg, height = 184.0 ± 10.0 cm, TE = > 2.0 yrs, 4RM BS = 129.0 ± 23.0 kg.	To determine the kinematic results of different ECC TEMPOS on a 4RM BS.	Exercise: BS, intensity 4RM, ECC TEMPO: TEMPO 1: participant's normal decent velocity, TEMPO 2: decent at a faster velocity than TEMPO 1. TEMPO 3: decent slower than normal velocity. All velocities were subjected to the participants in the study. The descent velocity was on average 0.3 $m \cdot s^{-1}$ faster and slower in TEMPO 2 and 3 velocities compared to the TEMPO 1, respectively. VDOWN: Negative acceleration before deceleration. V0: Lowest displacement of squat. VMAX1: Peak acceleration prior to sticking point. VMIN: Sticking point. VMAX2: Second peak velocity score.	VDOWN: Significant increase in displacement, velocity, and duration for TEMPO 2 vs TEMPO 1 and 3. V0: Significant increase in displacement for TEMPO 2 vs TEMPO 1 and 3. Significant increase in peak force for TEMPO 2 and 1 vs TEMPO 3. VMAX1: TEMPO 2 and 1 vs TEMPO 3 had significantly greater duration and velocity. VMIN: No difference in TEMPOS for measures assessed. VMAX2: No difference in TEMPOS for measures assessed.
Wilk [66]	N = 33 male, age = 24.0 ± 4.2 yrs, BM = 77.3 ± 5.7 kg, BP 1RM = 107.4 ± 13.5 kg, TE: 2.2 ± 0.6 yrs.	The effects of 2 s and 6 s ECC cadence on concentric power and velocity.	Exercise: BP, volume: 3 x failure, intensity: 70% of 1RM, ECC tempos: ECC-2s: 2s ECC, X CON ECC-6s: 6s ECC, X CON	Increase in mean velocity ($m \cdot s^{-1}$) for ECC-2s vs ECC-6s: Set 1 (15.38%), Set 2 (19.23%), Set 3 (21.57%). Increase in peak velocity ($m \cdot s^{-1}$) for ECC-2s vs ECC-6s: Set 1 (14.49%), Set 2 (17.14%), Set 3 (19.12%). Increase in mean power (W) for ECC-2s vs ECC-6s: Set 1 (16.46%) Set 2 (20.00%), Set 3 (23.97%). Increase in peak power (W) for ECC-2s vs ECC-6s: Set 1 (18.71%), Set 2 (19.45%), Set 3 (26.64%). Significant increase for ECC-2s vs ECC-6s: groups for all sets and all metrics.
Carzoli [89]	N = 16 trained males age = 23.6 ± 2.8 yrs, height = 171.8 ± 7.5 cm, BM = 82 ± 12.2 kg, BS 1RM = 151.8 ± 49.6 kg,	To determine the effects of different ECC TEMPOS on average and peak power scores.	Exercise: BS and BP, intensity: 60 and 80% of 1RM during both exercises. ECC TEMPOS: Controlled by metronome:	Increase in BS mean CON velocity ($m \cdot s^{-1}$) 60% 1RM: TEMPO 1 vs TEMPO 2 (8.06%), and TEMPO 3 (10.04%), TEMPO 1 significantly greater than both.

	BP 1RM = 119.7 ± 26.2, TE = 7.0 ± 3.6 yrs.		TEMPO 1: 0.75 times participant's normative ECC mean squat at 60 and 80% 1RM for both BS and BP. TEMPO 2: Normative. TEMPO 3: 2.00 times participant's normative ECC mean squat at 60 and 80% 1RM for both BS and BP.	Increase in BS peak CON velocity ($m \cdot s^{-1}$) 60% of 1RM: TEMPO 1 vs TEMPO 2 (74.44%) and TEMPO 3 (9.21%), TEMPO 1 significantly greater than both. Increase in BS mean CON velocity ($m \cdot s^{-1}$) 80% 1RM: TEMPO 1 vs TEMPO 2 (9.85%) and TEMPO 3 (17.65%), TEMPO 1 significantly greater than both. Increase in BS peak CON velocity ($m \cdot s^{-1}$) 80% of 1RM: TEMPO 1 vs TEMPO 2 (9.71%) and TEMPO 3 (10.04%), TEMPO 1 significantly greater than both. Increase in BP mean CON velocity ($m \cdot s^{-1}$) 60% 1RM: TEMPO 1 vs TEMPO 2 (10.66%) and TEMPO 3 (1.47%), TEMPO 1 and 3 significantly greater than TEMPO 2. Increase in BP peak CON velocity ($m \cdot s^{-1}$) 60% 1RM: TEMPO 1 vs TEMPO 2 (10.03%) and TEMPO 3 (-1.17%), TEMPO 1 and 3 significantly greater than TEMPO 2. Increase in BP peak CON velocity ($m \cdot s^{-1}$) 80% 1RM: TEMPO 1 vs TEMPO 2 (10.06%) and TEMPO 3 (3.97%), TEMPO 1 was significantly greater than TEMPO 2.
Pryo [90]	N = 24 males, age 20.7 ± 1.7 yrs, height 176.3 ± 6.7 cm, BM = 84.0 ± 14.1 kg, and BP 1RM 101.5 ± 19.9 kg.	To determine the effects of various eccentric tempo durations on repetition completed and peak and mean power.	Exercise: BP, volume: repetitions till failure, intensity 80% of 1RM. ECC TEMPOS: TEMPO 1: 1/0/X/3, TEMPO 2: 4/0/X/3, TEMPO 3: 1/0/X/0, TEMPO 4: 4/0/X/0 CON phase velocity was maximized, averaging 1.55 ± 0.3 s across all tempo trials.	Greater increase in repetition completed for TEMPO 1 vs TEMPO 2 (70%) and TEMPO 3 vs TEMPO 4 (69.09%), both TEMPO 1 and 3 significantly greater. Increase in peak power (W) for TEMPO 1 vs TEMPO 2 (26.47%) and TEMPO 3 vs TEMPO 4 (19.44%) both TEMPO 1 and 3 were significantly greater. Increase in mean power (W) for TEMPO 1 vs TEMPO 2 (25.15%) and for TEMPO 3 vs TEMPO 4 (19.49) both TEMPO 1 and 3 were significantly greater.
Wilk [71]	N = 20 healthy female athletes, age = 27.3 ± 2.2 yrs; BM = 53.3 ± 7.7 kg, TE= 3.9 ± 0.63 yrs, close grip BP 1RM = 55.2 ± 9.5 kg, wide grip BP 1RM = 52.7 ± 8.5 kg.	To determine the effects of different ECC tempos on close and wide grip BP repetitions to failure.	Exercises: close grip BP and wide grip BP, volume: 5 x CON failure, intensity: 70% of 1RM. ECC TEMPOS: ECC-2s: 2/0/X/0, ECC-6s: 6/0/X/0,	Increase in total reps ECC-2s vs ECC-6s for close (20.99%) and wide grip BP (19.85%), ECC-2s was significantly greater for both. Increase in TUT for ECC-6s vs ECC-2s for close (36.19%) and wide grip BP (28.67%), ECC-6s was significantly greater for both.
Sampson [91]	N = 12 recreational trained males age = 26.0 ± 3.9 yrs, height = 180.5 ± 7.9 cm, and BM = 79.1 ± 11.9 kg.	To determine the effects of different bicep curl techniques on repetition velocity,	Bicep curl via specialised flywheel device on dominant arm. Volume: 1 x repetition to failure with each protocol. ECC-X: X/0/X/0	No difference between groups for total workload (j). Greater amount of TUT (s) between ECC-2s vs ECC-X (18.75%). Significantly greater repetition mean velocity ($m \cdot s^{-1}$) for ECC-X vs ECC-2s during the first 3 repetitions

		TUT and total workload.	ECC-2s: 2/0/X/0	
Wilk [92]	N = 90 healthy males age = 25.8 ± 5.3 yrs, BM = 80.2 ± 14.9 kg, TE = 3.9 ± 4.2 yrs.	To determine the effects of different ECC tempos on 1RM BP performance.	BP 1RM ECC-V: V/0/V/0 (voluntary tempo), ECC-2s: 2/0/V/0, ECC-5s: 5/0/V/0, ECC-8s: 8/0/V/0, ECC-10s: 10/0/V/0.	Increase in 1RM score ECC-V vs ECC-2s (0.41%), ECC-5s (6.68%), ECC-8s (13.35%), ECC-10s (14.64%). ECC-V was significantly greater than ECC-5s, ECC-8s and ECC-10s. Increase in 1RM score ECC-2s vs ECC-5s (6.24%), ECC-8s (12.89%), ECC-10s (14.16%), ECC-2s was significantly greater than ECC-5s, ECC-8s and ECC-10s. Increase in 1RM score ECC-5s vs ECC-8s (6.26%) and ECC-10s (7.46%), ECC-5s was significantly greater than ECC-8s and ECC-10s.
Wilk [93]	N = 21 strength trained females, age = 23.4 ± 2.2 yrs, BM = 52.3 ± 6.7 kg, TE: 2.3 ± 1.5 yrs.	To determine the effects of different ECC tempos on 1RM performance.	1RM BP ECC-2s: 2/0/X, ECC-4s: 4/0/X, ECC-6s: 6/0/X.	Increase in BP 1RM score for ECC-2s vs ECC-4s (6.70%) and ECC-6s (9.85%), ECC-2s significantly greater than both. Increase in 1RM score for ECC-4s vs ECC-6s (2.97%) with a greater increase.
Calixto [67]	ECC-0.5s group: n = 8 males, age = 23.6 ± 0.4 yrs, BM = 81.0 ± 4.1 kg, height = 176.2 ± 1.2 cm, TE = 4.8 ± 0.9 yrs, 1RM ECC BS = 132.2 ± 7.7 kg. ECC-3s group: n = 8 males, age = 26.5 ± 0.6 yrs, BM = 76.3 ± 2.6 kg, height = 175.3 ± 0.8 cm, TE 5.6 ± 1.2 yrs, 1RM ECC BS = 120.8 ± 6.1 kg.	To determine the effects of ECC BS tempo durations on BL GH and total volume of load lifted.	Exercise: BS, volume 4 x 8 ECC only BS for both groups, intensity: 70% of 1RM, ECC TEMPOS: ECC-0.5s: 0.5 s ECC phase, ECC-3s: 3 s ECC phase.	ECC-0.5s had greater total volume of load lifted (9.2%), no difference between groups. Significant increase in BL (mM) during ECC-0.5s from pre to 0, 3, and 6-mins post exercise. Significant increase in BL (mM) during ECC-3s from PRE to 0, 3, 6-, 9-, 15-, and 20-mins post exercise. ECC-3s had greater increase in BL (mM) than ECC-0.5s at 3, 6-, 9-, 15-, and 20-mins post exercise. Peak BL (mM): ECC-3s vs ECC-0.5s (49.18%), ECC-3s was significantly greater than ECC-0.5s. GH ($ng \cdot mL^{-1}L$) post 15 mins: ECC-0.5s (0.1 ± 0.0), ECC-3s (1.7 ± 0.6), ECC-3s was significantly greater than ECC-0.5s.
Wilk [65]	N = 16 male, age = 21-29 yrs BM = 85.9 ± 7.7 kg, BP 1RM = 130.0 ± 17.5 kg, TE = 5.7 ± 1.3 yrs.	The effects of 2 s and 6 s ECC cadence BP on TUT, BL, CK, T and C.	Exercise: BP, volume: 5 x failure, intensity: 70% of 1RM, ECC tempos: ECC-2s: 2/0/2/0 and ECC-6s: 6/0/2/0.	ECC-2s achieved significantly greater volume than ECC-6s. ECC-6s achieved significantly greater TUT, LA, CK, T and C than ECC-2s.
Martins-Costa [94]	N = 15 male age = 24.4 ± 4.4 yrs, height = 177.0 ± 7.0 cm, BM = 78.3 ± 9.4 kg, BP 1RM = 93.4 ± 10.4 kg, TE = >6.0 mon.	To determine the effects of different ECC TEMPOS on IEMG and BL scores during the BP exercise.	Exercise: BP, volume: 3 x 6, intensity: 60% of 1RM, 3 min rest between sets. ECC TEMPOS: ECC-2s: 2 s ECC, 2 s CON. ECC-4s: 4 s ECC, 2 s CON. Blood samples taken after 10 mins of sit-down rest prior to study and 1 minute post set during testing.	ECC-4s vs ECC-2s had significantly greater IEMG Pectoralis major during all 3 sets. ECC-2s and ECC-4s had significantly greater activity during set 2 and 3 compared to set 1. ECC-4s had significantly greater IEMG tricep brachii during all 3 sets. ECC-2s and ECC-4s had significantly greater activity during set 3 compared to set 1.
				ECC-2s and ECC-4s had significantly greater BL (mM) scores from pre to all 3 sets. ECC-4s had significantly greater scores compared to ECC-2s during all 3 sets. ECC-2s and ECC-4s had significantly greater BL (mM) post set 3 compared to 1 and 2. ECC-2s and ECC-6s had significantly greater BL (Mm) post set 2 compared to 1.

N: Sample size, **YRS**: years, **MON**: Months, **BM**: Body mass, **kg**: Kilograms, **TE**: Training experience, **1RM**: One repetition maximum, **RM**: Repetition maximum, **ECC**: Eccentric, **CON**: Concentric, **TEMPO**: Eccentric/isometric/concentric/isometric, **TUT**: Time under tension, **X**: Fast as possible, **BL**: Blood lactate, **CK**: Creatine kinase, **S**: Seconds, **MINS**: Minutes, **GH**: Growth Hormone, **CK**: Creatine Kinase, **T**: Testosterone, **C**: Cortisol, **BS**: Back squat, **BP**: Bench Press, **iEMG**: integrated electromyography.

Table 4: Acute isokinetic dynamometer studies

Author	Population	Aim	Method	Findings
Shepstone [53] study part 2.	N = 9 recreationally active (no weight training and no more than 1 structured exercise bout per week) males age = 23.2 ± 2.4 yrs, height = 181.9 ± 6.1 cm, BM = 81.1 ± 5.6 kg.	To determine the effects of 210°·s^{-1} and 20°·s^{-1} ECC IKD on Z line streaming.	Exercise: ECC IKD maximal arm lengthening. Volume: 3 x 10, rest: 3 min rest between sets. IKD testing values: 210°·s^{-1} and 20°·s^{-1}. Z-line streaming obtained from muscle biopsy.	ECC-210°·s^{-1}and ECC-20°·s^{-1}significantly increased z-line streaming, ECC-210°·s^{-1}was significantly greater that ECC-20°·s^{-1}. No significant increase in Extreme – moderate for both groups. Z-band streaming. (encompassing >10 serially or longitudinally adjacent sarcomeres with damage).
Roschel [54]	ECC-210°·s^{-1} group n = 9 males, age = 26.4 ± 4.3 yrs, height = 177.0 ± 3.0 cm, BM =76.3 ± 9.6 kg. ECC-20°·s^{-1} group n = 11 males, age = 25.4 ± 5.0 yrs, height = 176.0 ± 6.0 cm, BM = 77.2 ± 10.5 kg.	To determine the effects of 210°·s^{-1} and 20°·s^{-1} ECC IKD on total work, peak torque, total protein, and protein phosphorylation, mTOR, p70^{S6k1}, Mechano growth factor, mRNA, Akt phosphorylation expression, mTOR phosphorylation and p70^{S6k1}.	Exercise: ECC IKD Knee extension (0° to 90°). Volume: 5 x 8, rest: 3 min rest between sets. Testing values: 210°·s^{-1}and 20°·s^{-1}	No difference between groups for: Total work, peak torque total protein and protein phosphorylation, Mtor, p70^{S6k1}. Significant increase for ECC-20°·s^{-1}group in baseline and 2 hours post exercise for; Mechano growth factor and mRNA expression. Significant increase for both groups in; Akt phosphorylation from baseline to immediately post and 2 hours post exercise, mTOR phosphorylation immediately after exercise and p70^{S6k1} immediately after exercise and post 2 hours exercise.
Cress [25]	N = 30 females: age = 25.0 ± 2.6 yrs.	To determine the effects of various IKD torque values to determine changes in muscle force during leg extension.	Exercise: ECC IKD (right) leg extension, testing angular velocities: 30, 60, 90, 120, 150, 180, and 210°·s^{-1}.	No significant difference between testing values.
Drury [95]	N = 11 healthy males age = 19.8 ± 1.6 yrs, height = 179.7 ± 3.8 cm, BM = 84.2 ± 14.7 kg, TE = >6.0 mon.	To determine the effects of different angular velocities on peak torque during an IKD bicep curl.	Exercise: Bicep curl, extension 170° and flexion 45° Testing torque values: 90, 180, and 300°·s^{-1}.	No significant difference between testing torque values.
Hortobágyi [96]	40 males, Group 1: n = 20, age = 22.6 ± 5.0 yrs, BM = 76.6 ± 11.5 kg, height = 178.0 ± 9.0 cm. Group 2: n = 20, age = 23.1 ± 1.8 yrs, BM = 90.9 ± 3.3 kg, height = 178.0 ± 7.0 cm.	To determine the effects of peak torque during IKD ECC arm flexion.	Exercise: Arm flexion and extension Testing values: 30, 90, and 120°·s^{-1}. Group 1: low strength group, Group 2: high strength group. Groups were selected by the participant's strength levels.	No significant difference in torque values for group 1. Significant increase for group 2 during 30–120°·s^{-1} values for both flexion (8.70%) and extension (6.49%).

N: Sample size, **YRS**: years, **MON**: Months, **BM**: Body mass, **kg**: Kilograms, **TE**: Training experience, **CM**: Centimetres, **ECC**: Eccentric, **°·s^{-1}**: Degrees per second, °: Degrees, **MINS**: Minutes, **IKD**: Isokinetic dynamometry.

Table 5: Chronic tempo training studies.

Author	Population	Aim	Method	Findings
Mike [97]	N = 30 males ECC-2s: age = 22 ± 2.1 yrs, height = 180.0 ± 6.6 cm, BM = 79.0 ± 5.4 kg, TE: 3.1 ± 0.9 yrs, BS 1RM = 124.0 ± 20.0 kg. ECC-4s: age = 22.0 ± 2.1 yrs, height = 176.0 ± 4.8 cm, BM = 82.0 ± 12.0 kg, TE = 2.8 ± 1.1 yrs, BS 1RM = 129.0 ± 22.0 kg. ECC-6s: age = 23.0 ± 4.2 yrs, height = 178.0 ± 8.4 cm, BM = 85.0 ± 16.7 kg, TE = 2.8 ± 1.1 yrs, BS 1RM = 129.0 ± 22.0 kg.	To determine the effects of different ECC TEMPOS on various performance metrics.	Duration: 4-weeks 2 x days per week for 8 sessions. Sessions 1–4, volume: 4 x 6, intensity 80% of 1RM, exercise: BS. Sessions 5–8, volume: 4 x, intensity: 85% of 1RM. Rest: 3 min rest between sets. ECC tempos: ECC-2s: 2/1/2, ECC-4s: 4/1/2, ECC-6s: 6/1/2.	Increase in 1RM BS: ECC-2s (8.87%), ECC-4s (13.18%), ECC-6s (12.71%) no difference between groups. Increase in vertical jump height (inches): ECC-2s (4.5%), ECC-4s (1.4%) and ECC-6s (1.6%), ECC-2s significant increase. Significant decrease for ECC-2s for pre to post study perceived soreness 24, 48 and 72 hrs post training session. Significant decrease for ECC-4s for pre to post study perceived soreness 24 and 48 hrs post training session. Significant decrease for ECC-6s for pre to post study in perceived soreness 48 hrs post training session.
Pereira [69]	Gender of participants not identified. ECC-1s: age = 28.3 ± 8.2 yrs, height = 172.3 ± 5.3 cm, BM = 72.3 ± 9.3 kg, BF% = 17.3 ± 2.2%. ECC-4s: age = 30.3 ± 5.6 yrs, height = 172.6 ± 4.8 cm, BM = 73.8 ± 5.1 kg, BF% = 19.3 ± 0.9%.	To determine the effects of different ECC tempos Scott curls on bicep 1RM and CSA.	Duration: 12 weeks, 2 sessions per week. Volume: 3 x 8 maximum, load not identified. Exercise: Scott curl. ECC TEMPOS: ECC-1s: 1/0/1/0, ECC-4s: 4/0/1/2.	Increase in CSA (cm^2) ECC-1s (6.25%) and ECC-4s (16.55%). Greater increase with ECC-4s vs ECC-1s. Increase in 1RM (kg) ECC-1s (18.98%) and ECC-4s (32.40%). Greater increase with ECC-4s vs ECC-1s.
Stasinaki [68]	N = 18: ECC-1s: n = 5 males 4 females, age = 21.9 ± 0.7 yrs, height 173.4 ± 9.8 cm, BM = 65.2 ± 10.1 kg, TE = 0.0 yrs. ECC-4s: n = 5 males 4 females = age = 22.1 ± 2.0 yrs, height 170.4 ± 7.8 cm, BM = 67.7 ± 9.9 kg, TE = 0.0 yrs.	To determine the effects of different ECC tempos on performance variables.	Duration: 6-weeks, 2 sessions per week. Exercise: ECC only half BS. ECC-1s: ECC TEMPO: <1 s, volume: 9 x 9, intensity: 70% of 1RM, 3 min rest between sets. ECC-4s: ECC TEMPO: 4 s, volume: 5 x 6, intensity 90% of 1RM, 3 min rest between sets.	Increase in BS 1RM Squat ECC-1s (14.5 ± 7.0%) and ECC-4s (5.4 ± 5.1%), ECC-1s was significantly greater than ECC-4s. Increase in CMJ height ECC-1s (2.1 ± 7.6%), ECC-4s (1.3 ± 7.5%) no difference between groups. Increase in CMJ power ECC-1s (7.9 ± 22.2%), ECC-4s (–6.8 ± 7.8%), ECC-4s significantly decreased, no difference between groups. Increase in vastus lateralis muscle thickness: ECC-1s (3.1 ± 9.1%), ECC-4s (6.8 ± 7.8%), ECC-4s was significantly greater, no difference between groups. Increase in fascicle angle: ECC-1s (5.7 ± 15.5%), ECC-4s (7.8 ± 18.8%), no difference between groups. Increase in fascicle length: ECC-1s (10.0 ± 6.2%), ECC-4s (−3.1 ± 7.1%), significant increase from pre to post for ECC-1s and ECC-1s vs ECC-4s.
Douglas [43]	N = 14 male rugby academy players age = 19.4 ± 0.8 yrs, height = 182.0 ± 5.0	The effects of 2, 4-week AEL vs TRAD	2 Part training study.	Increase in relative back squat 1RM $kg.BM^{-1}$:
	cm, BM = 97.0 ± 11.6 kg, relative BS 1RM 1.7 ± 0.2 kg.BM-1, TE = > 1.0 yrs.	programmes performed at 1 s and 3 s ECC TEMPOS on performance variables.	Week 1–4: ECC TEMPOS: AEL3s: 3 s AEL, TRAD3s: 3 s TRAD. 2-weeks rest between programmes. Week 4–8: AEL1s: 1 s AEL, TRAD1s: 1 s TRAD eccentric phase.	AEL-1s (-0.54%), AEL-3s (5.03%), TRAD-1s (0.63%), TRAD-3s (-1.82%). 0.50-m drop jump variables Increase in contact time (s): AEL-1s (-9.09%), AEL-3s (0.00%), TRAD-1s (0.00%), TRAD-3s (0.00%). Increase in flight time (s): AEL-1s (-2.04%), AEL-3s (0.00%),

				TRAD-1s (0.00%), TRAD-3s (2.22%). Increase in RSI: AEL-1s (5.54%), AEL-3s (0.00), TRAD-1s (0.51%), TRAD-3s (1.03%). Leg stiffness (kM.m.kg-1) AEL-1s (17.86%), AEL-3s (0.00%), TRAD-1s (4.00) TRAD-3s (-3.85%). Increase in muscle thickness (cm): AEL-1s (3.23%), AEL-3s (3.33%), TRAD-1s (3.12%), TRAD-3s (0.00%). Increase in fascicle angle (θ): AEL-1s (5.04%), AEL-3s (-3.47%), TRAD-1s (3.31%), TRAD-3s (0.00%). Increase in Fascicle length (cm): AEL-1s (-6.77%), AEL-3s (9.02%), TRAD-1s (-0.80%), TRAD-3s (-0.79%).
Shibata [98]	ECC-2s group: n = 11, age = 19.8 ± 0.9 yrs, height = 170.7 ± 3.1 cm, and BM = 65.6 ± 4.9 kg. ECC-4s group: n = 11, age = 19.9 ± 1.0 yrs, height = 173.6 ± 4.0 cm, BM = 66.6 ± 8.1 kg.	To determine the effects of different ECC TEMPOS on performance variables.	Duration: 6 weeks 2 x sessions per week. Exercise: BS, volume: 3 x failure, intensity: 75% of 1RM, ECC TEMPOS: ECC-2s: 2 s ECC, 2 s CON ECC-4s: 4 s ECC, 2 s CON	No difference in TUT and volume between 2 s and 4 s. 2 s and 4 s increase in CSA at distal, proximal, and mid, no difference between groups. Increase in BS 1RM ECC-2s (18.46%) and ECC-4s (10.46%), greater increase in ECC-2s vs ECC-4s. Increase in CMJ and SJ jump height, no difference between ECC-2s vs ECC-4s. No change in T-Test and YoYo run for both groups.
Kojić [70]	N = 11 males 9 females. ECC-1s group: age = 24.5 ± 2.2 yrs, height = 178.0 ± 7.0 cm, BM = 72.2 ± 13.5 kg. ECC-4s group: age = 23.6 ± 0.9 yrs, height = 172 ± 8.0 cm, BM = 68.6 ± 11.6 kg.	To determine the difference of different ECC tempo on biceps brachii thickness and 1RM.	Duration: 7 weeks, 2 x sessions per week. Exercise: bicep curl. Weeks 1 – 3, volume: 3 x failure, intensity: 60% of 1RM, Weeks 4 – 7, volume: 4 x failure, intensity: 70% of 1RM. ECC TEMPOS: ECC-1s: 1/0/1/0, and ECC-4s: 4/0/1/0.	Increase in bicep brachii thickness: ECC-1s (15.4%), ECC-4s (18.3%), significantly greater increase in ECC-4s vs ECC-1s. Increase in 1RM: ECC-1s (11.6%), ECC-4s (23.5%), significantly greater increase in ECC-4s vs ECC-1s.

N: Sample size, **YRS**: years, **BM**: Body mass, **kg**: Kilograms, **CM**: Centimetres, **TE**: Training experience, **BF%**: Body fat percentage, **1RM**: One repetition maximum, **ECC**: Eccentric, **CON**: Concentric, **TUT**: Time under tension, **TEMPO**: Eccentric/isometric/concentric/isometric, **CSA**: Cross sectional area, **MINS**: Minutes, **S**: Seconds, **BS**: Back squat, **BP**: Bench Press, **CM**: Countermovement jump, **AEL**: Accentuated eccentric loading, **TRAD**: Traditional.

Table 6: Chronic isokinetic dynamometer studies.

Author	Population	Aim	Method	Results
Farthing [56]	ECC-180°·s^{-1}: n = 4 males, 9 females, age = 21.9 ± 1.5 yrs, BM = 65.6 ± 3.8 kg, height 167.0 ± 2.0 cm, TE = 1.2 ± 0.7 mon. ECC-30°·s^{-1}: n =7 males 6 females, age = 19.4 ± 0.6 yrs, BM = 74.3 ± 3.0 kg height = 175.0 ± 2.1 cm, TE = 2.3 ± 0.8 mon. CT: n = 2 males, 8 females, age = 22.7 ± 0.9 yrs, 65.2 ± 3.2 kg, height = 169.0 ± 2.6 cm. 2.3 ± 0.8, TE 2.3 ± 1.1 mon.	To determine the effects of ECC IKD at 180°·s^{-1} and 30°·s^{-1} on performance variables.	Duration: 8 weeks, 3 sessions per week, a total of 24 training sessions. Volume: progressive increase from 2 to 6 sets of 8 maximal repetitions per training session over the first 13 training sessions, 6 sets for training sessions 13-22, and a taper down to 3 sets of 8 maximal repetitions prior to post-testing during training sessions 23 and 24. Training torque values: ECC-180°·s^{-1}: 180°·s^{-1} and ECC-30°·s^{-1}: 30°·s^{-1}. 100° range of motion, approximately 60º to 160º elbow extension for eccentric contractions.	Trained arm peak torque (Nm) % increase at ECC 180°·s^{-1}: ECC-180°·s^{-1} (23.73%), ECC-30°·s^{-1} (-5.56%), CT (8.62%). ECC-180 vs CT was significantly greater post study. Trained arm peak torque (Nm) % increase at ECC 30°·s^{-1}: ECC-180°·s^{-1} (23.21%), ECC-30°·s^{-1} (-7.14), CT (8.93%). ECC-180°·s^{-1} vs CT was significantly greater post study. Trained arm peak torque (Nm) % increase at CON 180°·s^{-1}: ECC-180°·s^{-1} (29.73%), ECC-30°·s^{-1} (-2.22%), CT (22.58%). ECC-180°·s^{-1} and ECC-30°·s^{-1} vs CT was significantly greater post study. Trained arm peak torque (Nm) % increase at CON 30°·s^{-1}: ECC-180°·s^{-1} (34.29%), ECC-30°·s^{-1} (-4.26%), CT (11.76%). ECC-180°·s^{-1} and ECC-30°·s^{-1} vs CT was significantly greater post study+. No significant increase at the proximal site for the trained arm for all groups. Increase in muscle thickness mid-site: ECC-180°·s^{-1} (12.50%), ECC-30°·s^{-1} (8.56%), CT (-3.13%), Both ECC-180°·s^{-1} and ECC-30°·s^{-1} significantly increased from pre to post. Increase in muscle thickness distal site: ECC-180°·s^{-1} (14.71%), ECC-30°·s^{-1} (10.81%), CT (0%). Both ECC-180°·s^{-1} and ECC-30 ·s^{-1} significantly increased from pre to post.
Farthing [55]	ECC-180°·s^{-1} group n = 4 males, 9 females, age = 21.9 ± 1.5 yrs, BM = 65.6 ± 3.8 kg, height = 167.1 ± 2.2 cm, TE = 1.2 ± 0.6 MON. ECC-30°·s^{-1} group n = 7 males, 4 females age = 19.6 ± 0.7 yrs, BM = 74.6 ± 3.5 kg, height = 175.7 ± 2.3 cm, TE = 2.7 ± 1.1 MON, CT: n = 2 males, 8 females age = 22.7 ± 0.9 yrs height = 168.8 ± 2.6 cm BM 65.2 ± 3.2 kg TE = 2.3 ± 1.1 MON.	To determine the effects of 180°·s^{-1} and 30°·s^{-1} ECC IKD on performance variables.	Duration: 8 weeks, 3 sessions per week, 24 training sessions. Exercise: elbow flexion, training torque values: ECC-180°·s^{-1}: 180°·s^{-1}, ECC-30°·s^{-1}: 30°·s^{-1} and CT. Volume: 2-6 sets x 8 maximal repetitions per training session over the first 13 training sessions. 6 sets for training sessions 13–22 and a taper down to 3 x 8 maximal repetitions prior to post testing (training sessions 23 and 24).	Increase in combined sites (proximal, mid, and distal) muscle thickness: ECC-180°·s^{-1} (13%), ECC-30°·s^{-1}, (7.8%), CT (-0.8%). ECC-180°·s^{-1} and ECC-30°·s^{-1} vs CT was significantly greater Significantly greater increase in ECC torque at 180°·s^{-1} and 30°·s^{-1} for ECC-180°·s^{-1}vs ECC-30°·s^{-1} and CT. Significantly greater increase in CON torque at 180°·s^{-1} and 30°·s^{-1}, for ECC-180°·s^{-1} vs CT.
Shepstone [53] study 1	N = 12 male age 23.8 ± 3.4 yrs, height = 178.5 ± 9.6 cm, BM = 82.5	To determine the effects of 210°·s^{-1} and 20°·s^{-1}	Duration: 8 weeks, 3 sessions per week. Volume: week 1: 1 x 10, week	Increase in peak torque (N.m) at torque testing values of 20, 60, 120, 180 and 210°·s^{-1}during both ECC and CON muscle actions:

	± 10.3 kg. Not engaged in RT 6 MON prior to the study.	ECC IKD on performance variable in a training study.	2: 2 x 10, week 3: 3 x 10, weeks 4–8: 4 x 10 with 180 s rest between sets. Exercise: elbow arm flexion. ECC training torque values: ECC-210°·s^{-1}: 210°·s^{-1} and ECC-20°·s^{-1}: 20°·s^{-1}	ECC-20°·s^{-1}and ECC-210°·s^{-1} increased from pre to post, ECC-210°·s^{-1} had a greater improvement than ECC-20°·s^{-1}. Increase in CSA from pre to post: ECC-210°·s^{-1} had significantly greater increase vs ECC-20°·s^{-1}. Increase in muscle fibre size type Ia for pre to post study: both ECC-210°·s^{-1} and ECC-20°·s^{-1} significantly increased. Increase in muscle fibre size type IIa for pre to post study: both ECC-210°·s^{-1} and ECC-20°·s^{-1} significantly increased, ECC-210°·s^{-1} vs ECC-20°·s^{-1} had a greater increase. Increase in muscle fibre size type IIx for pre to post study: both ECC-210°·s^{-1} and ECC-20°·s^{-1}, significantly increased, ECC-210°·s^{-1} vs ECC-20°·s^{-1} had a greater increase. Increase in muscle fibre % pre to post study: Type Ia: ECC-210°·s^{-1} (-9.81%), ECC-20°·s^{-1} (10.18%). Type IIa: ECC-210°·s^{-1} (10.65%) ECC-20°·s^{-1} (-1.61%). Type IIx: ECC-210°·s^{-1} (-25.27%) ECC-20°·s^{-1} (-34.51%), significant decrease for both ECC-210°·s^{-1} and ECC-20°·s^{-1}. Increase in muscle fibre area % from pre to post study: Type Ia: ECC-210°·s^{-1} (-16.52%), ECC-20°·s^{-1} (4.92%). Type IIa: ECC-210°·s^{-1} (14.43%), ECC-20°·s^{-1} (2.93%), ECC-210°·s^{-1} significantly improved from pre to post and significantly greater vs ECC-20°·s^{-1}. Type IIx ECC-210°·s^{-1} (-34.12%) ECC-20°·s^{-1} (-34.41%). Increase in myosin heavy chains %: Type Ia: ECC-210°·s^{-1} (18.77%) ECC-20°·s^{-1} (-7.84). Type IIa: ECC-210°·s^{-1} (21.26%) ECC-20°·s^{-1} (14.79%), both ECC-210°·s^{-1} and ECC-20°·s^{-1} significantly increased from pre to post study and ECC-210°·s^{-1} vs ECC-20°·s^{-1} was significantly greater. Type IIx: ECC-210°·s^{-1} (-42.50) ECC-20°·s^{-1} (-31.34%), both significantly decreased.
Paddon-Jones [58]	N = 20 non-resistance trained males and females age = 24.2 ± 7.0 yrs, height = 176.6 ± 5.9 cm, BM 76.2 ± 15.8 kg. ECC-180°·s^{-1}: n = 5 male 2 female. ECC-30°·s^{-1}: n = 5 male 1 female. CT: n = 5 males 2 females.	To determine the effects on torque and muscle fibre change when completing either 180°·s^{-1} or 30°·s^{-1} IKD ECC training.	Duration: 3 non consecutive days for 10 weeks Volume: 4 x 6 repetitions 60 s rest between sets. Exercise: non dominant arm flexion. ECC IKD values: ECC-180°·s^{-}1: 180°·s^{-1} and ECC-30°·s^{-1}: 30°·s^{-1}	Significant increase in isometric torque for ECC-180°·s^{-1} group from pre to post and compared to CT group. Increase in CON torque at 30°·s^{-1}: no significant increase for any group from pre to post. Increase in CON torque at 180°·s^{-1}: Significant increase from pre to 5 weeks for both ECC-180°·s^{-1} and ECC-30°·s^{-1} groups. Post ECC-30 ·s^{-1} and CT.

				Increase in ECC torque 30°·s^{-1}: ECC-180°·s^{-1} had significantly greater improvement post study vs ECC-30°·s^{-1} and CT. Increase ECC torque 180°·s^{-1}: ECC-180 had significantly greater improvement post study vs CT. Increase in muscle fibre changes: ECC-180°·s^{-1} significant increase type IIb but significantly decreased type Ia fibre from pre to post. No significant difference between the other groups.
Ünlü [60]	20 males, ECC-180°·s^{-1}: n = 6, age = 20.5 ± 1.9 yrs, BM = 72.8 ± 8.2 kg, height = 187.8 ± 8.5 cm. ECC-30°·s^{-1}: n = 7, age = 21.6 ± 0.5 yrs, BM = 68.7 ± 8.2 kg, height = 176.7 ± 4.9 cm. CT: n = 7, 21.3 ± 2.4 yrs, BM = 67.6 ± 8.8 kg, height = 178.4 ± 6.3 cm.	To determine the effects of completing either 180°·s^{-1} or 30°·s^{-1} isotonic leg extension during a 12-week programme on performance variables.	Duration: 12-week training programme in respected group. 3 x per week. Exercise: isotonic knee extension. ECC-180°·s^{-1}: ECC only at 180°·s^{-1}, 100-155% or 1RM and time under load per set 8 – 10 s. ECC-30°·s^{-1}: ECC only at 30°·s^{-1}, 80-85% or 1RM, time under load per set 30–40 s CT: Non training control group.	Increase in 1RM: ECC-180°·s^{-1} (28.5%), ECC-30°·s^{-1} (36.5%), CT (-0.6%), ECC-180°·s^{-1} and ECC-30°·s^{-1} had greater increase than CT. Increase in peak torque CON 60°·s^{-1}: ECC-180°·s^{-1} (13.5%), ECC-30°·s^{-1} (24.9%), CT (-0.8%), ECC-180°·s^{-1} and ECC-30°·s^{-1} had a greater increase than CT. Increase in peak torque CON 180°·s^{-1}: ECC-180°·s^{-1} (15.10%), ECC-30°·s^{-1} (17.00%), CT (3.00%), ECC-180°·s^{-1} and ECC-30°·s^{-1} had a greater increase than CT. Increase in muscle volume (cm^3): ECC-180°·s^{-1} (4.14%), ECC-30°·s^{-1} (10.04%), CT (3.75%). No difference between groups.

N: Sample size, **YRS**: years, **BM**: Body mass, **kg**: Kilograms, **TE**: Training experience, **M**: Meters, **CM**: Centimetres, **ECC**: Eccentric, **CON**: Concentric, **°s^{-1}**: Degrees per second, °: Degrees, **HRS**: Hours, **MINS**: Minutes, **MON**: Months, **CT**: Control, **1RM**: One Repetition Maximum.

4.0 Discussion

4.1 Eccentric Torque Velocity Relationship

The results of this review indicate that during eccentric IKD greater forces can be achieved when angular velocities >180°·s^{-1} is performed when compared to <180°·s^{-1} [14,16,78,99,100] and some studies indicated that there are no difference in torque value when values of 180°·s^{-1} and above are performed [25,54,95,101] (Table 4). The chronic effects of utilising eccentric IKD identified that 180 and 210°·s^{-1} angular velocity value groups improved all tested angular velocity metrics [53,55,56,58], whereas the 20 and 30°·s^{-1} groups did not [53,55,56,58] (Table 6). These findings are in agreement with Kellis and Baltzopoulos' [52] review which explained that the eccentric IKD is not velocity specific. The increase in torque value results are expected as eccentric torque values are enhanced or maintained when there is an increase in velocity [23,102–104]. Therefore, participants will increase force production and overall strength capacity of the muscle through physiological factors e.g., increasing motor unit recruitment [3,102]. When eccentric actions are performed maximally a greater muscular action will occur, therefore, an increase in motor unit recruitment will arise [102]. This with the addition of Titin being thought to enhance force production a greater muscle action could achieve subsequent enhanced physiological adaptions occur [30–33]. This concurs with Verkoshansky and Siff [13] who state faster actions have a better transfer to slow actions than vice versa.

Farthing and Chilibeck [56] found chronic 180°·s^{-1} eccentric IKD increased concentric peak torque at 180 and 30°·s^{-1}. Paddon-Jones [58] observed 180°·s^{-1} eccentric IKD increased concentric peak torque at 180°s^{-1} but neither 180°s^{-1} or 30°s^{1} increased concentric peak torque testing values (Table 6). Previous findings are mixed for mode specific IKD and very little research has viewed two different eccentric torque values in relation to increasing concentric strength (Table 6). From these results it can be hypothesised 180°·s^{-1} eccentric IKD could enhance concentric IKD torque values greater than <180°·s^{-} IKD scores however, future research is required to define a definitive conclusion.

4.2 Eccentric Tempo Acute Response

Acute studies investigating the impact of reduced durations of movement on concentric power and/or velocity found a <2 s eccentric duration significantly increased power and velocity [66,81,89–91] in subsequent concentric performance (Table 3). Schoenfeld [105] commented that slower tempos lead to less concentric force, power and reduced stretch shortening cycle (SSC) via a reduced recruitment of type IIx muscle fibres. Carzoli et al. [89] highlighted through completion of faster eccentric actions during both back squat and bench press with 60 and 80% of 1RM a subsequent enhancement of concentric average and peak velocities (Table 3). It can be suggested that these findings occur from a better response of SSC [106] and faster eccentric muscle actions achieve a greater effect of type IIa and IIx muscle fibres [78] and motor unit recruitment. However, only one study in the current review analysed eccentric kinematics results [81]. Therefore, future research must address this method so a more definitive conclusion can be addressed.

Several acute studies investigating the impact of tempo on strength values have indicated that faster eccentric tempos elicit greater strength values throughout a whole exercise movement [72,93,97] (Table 3). In multiple acute studies Wilk [72,93,97] demonstrated that the shorter duration tempo e.g., faster movement produced the highest 1RM value for bench press. These differences were notably found in movements of <2 s eccentric phases compared to 4 and 6s [72] and 5, 8 and 10s [97] (Table 3). These findings reinforce the effects on concentric performance such as an improved SSC response, use of stored elastic energy [23,78,107,108], and faster eccentric velocities can result in the recruitment of higher threshold motor units [3,109]. Future research needs to determine if performing eccentric phases <2 s has any greater effects on 1RM performance.

4.3 Eccentric Tempo Chronic Response

During chronic based studies to determine if 1RM increased utilising specific eccentric phase durations across the same loads, a <2 s eccentric durations significantly increased back squat 1RM when compared to 4 s eccentric durations which did not [68,98] (Table 5). However, findings on eccentric tempos are equivocal with Mike [97] finding no difference in 1RM values between 2, 4 and 6 s eccentric phase (Table 5). Further, Kojić [70] found that 4 s eccentric duration had a greater 1RM increases than 1 s eccentric tempos (23.5% vs 11.6%, respectively), though both groups demonstrated significant strength increases. One explanation for this result is that the 4 s group would have undergone significantly greater time under tension (TUT) and the 1 s group had demonstrated significantly greater muscle volume increases which led to the concomitant increase in strength. Ünlü [60] found no difference between 30 and 180°·s^{-1} isotonic leg extension during eccentric actions. Douglas [43] found the largest effect size during the 3 s AEL method to improve relative 1RM back squat, whereas, 3 s traditional decreased scores and 1 s traditional slightly improved performance (Table 5).

The aforementioned chronic studies' findings indicate no clear duration which achieves a greater 1RM enhancement (Table 5). Findings from Kojić [70] could speculate the 4 s group had greater TUT and hypertrophic gain post study, which may have factored why there was an increase in 1RM. Furthermore, during the study by Douglas [43] results indicated the 3 s AEL method achieved the greater improvement when compared to the other methods. Though, it could be speculated to be an increase in motor learning as each training programme lasted for 4 weeks. The acute findings of utilizing a <2 s eccentric tempo indicate an increase in peak and mean power per repetition and 1RM increase. Though long-term training effects do not yield the same benefits of the acute findings.

4.4 Work and Time Under Tension

TUT is the amount of time a muscle is held under tension or strain during an exercise set and therefore is the product of duration in seconds in relation to how many repetitions are completed. When performing reduced tempo durations compared with longer durations the amount of TUT will be less. However, performing a reduced duration (faster tempo) enables performance of more repetitions [64]. The methodology behind this is, though participants complete repetitions in a faster duration, they are able to complete more volume, subsequently, increasing TUT [63,64,70,105]. This is solidified within the acute studies of [65,91] (Table 3), chronic study of Kojić [70] (Table 5) and further support by Pryo [90] which indicated a higher total number of repetitions during a 1 s eccentric tempo but did not show TUT results.

An important finding our review discovered is a number of studies viewed two different velocity, torque, or duration values against one another. However, both training methods completed the same volume [65,67,94] (Table 5 and 6). One could argue these comparative studies did not fulfil a similar protocol. Though, the same volume is completed, metrics such as impulse and TUT will differ as the duration of the exercise is different. This identifies that the same displacement was complete but with a reduced time and thus achieving a greater velocity, resulting in a greater impulse. This is likely to factor results such as TUT, blood lactate (BL) and therefore, hypertrophic response and strength improvements during chronic studies [110,111].

4.5 Eccentric Execution Effects on Hypertrophy

Eccentric training has been shown to increase hypertrophic gains greater than concentric training only [12,14,105,112] via an increase in protein synthesis and IGF-1 mRNA expression as well as increases in testosterone and growth hormone [105,110,113]. During acute tempo studies (Table 3) Wilk [65] identified that a 6 s eccentric phase created larger TUT, BL, creatine kinase (CK) and serum testosterone compared to 2 s. Calixto [67] had participants perform back squat with either 3 s or 0.5 s eccentric phase durations with the 3 s group demonstrating significantly higher peak BL, 3, 6, 9, 15 and 20 mins post exercise BL and post 15 min growth hormone compared to the 0.5 s. Martin-Costa [94] found a 4 s eccentric phase created a larger accumulation of BL post 1 minute after 3 sets. Though the aforementioned studies [65,67,94] (Table 3 and 4) show metrics such as testosterone and BL are enhanced during the longer durations tempos, caution must be taken when analyzing these results. As they all performed the same amount of volume with the same mass during the studies, thus the tempos that are larger in duration will likely achieve a greater amount of TUT increasing BL which is correlated with an increase in growth hormone response [110,111].

Shepstone [53] used a IKD protocol and highlighted moderate z-band disruption was greater for 210°·s^{-1} compared to 20°·s^{-1}, though extreme z-band disruption was not significant between groups, z-line streaming suggests myofibrillar remodelling which leads to increase in muscle size [105] (Table 4). Nogueira [114] found no significant difference between 20°·s^{-1} and 210°·s^{-1} for mechano-growth factor, total Akt, total mTOR and P70^{S6k1}. However, both groups significantly improved from pre to immediately after and 2 hours post exercise for phospho-Akt and P70^{S6k1} phosphorylation and both groups significantly improved phosphor-mTOR immediately after. Though, 20°·s^{-1} showed that total impulse was greater (Table 4). Physiological occurrences such as MTOR and Akt are indictive of anabolic signalling pathway, however, the limited results presented in the current review identify no clear distinction between the training angular velocity values.

Stasinaki [68] found no difference between <1 s (as fast as possible under control) and 4 s eccentric only back squat for both vastus lateralis muscle thickness and fascicle angle (Table 5). However, the <1 s group showed significant differences compared to the 4 s group for fascicle length. Douglas [115] concluded there was no clear difference between 1 s and 3 s (eccentric phase) traditional and AEL methods for muscle thickness and fascicle angle and length (Table 5). It is important to note that both programmes only lasted for 4-weeks which may have indicated no increase in muscle mass due to the physiological timelines needed to show muscle mass alterations is typically longer than 4 weeks. Shibata [98] had increases in cross-sectional area (CSA) but no difference between groups when comparing 2s eccentric and concentric and 4s eccentric 2s concentric during back squat to failure. Kojić [70] highlighted no difference in bicep brachii muscle mass gain for 1s and 4s eccentric despite the 4s group achieving significantly greater eccentric TUT, though, the 1s group performed significantly greater concentric TUT which has been shown to increase CSA [67,110] (Table 5). In conjunction with this, Fisher's [116] review commented that there is no significant correlation between repetition duration and muscular hypertrophy. This is further supported by Schoenfeld [117] who states there is no distinct difference between 0.8-8s of total repetition duration with respect to muscle hypertrophy and eccentric duration should range from 2–4s. Krzysztofik [63] further adds more research is needed [117] though eccentric phase durations of <2s show promise for increasing muscle mass.

The current review further identifies IKD methods of 180-210°$\cdot$s^{-1} and 20-30°$\cdot$s^{-1} have been compared to determine if increased angular velocity values create significant muscle mass difference (Table 6). The studies by Farthing and Chilibeck [55,56] found no difference in increases for proximal, distal and mid site muscle thickness (Table 6). However, one study [55] classified 180°$\cdot$s^{-1} as a greater method to attain larger muscle thickness gains due to a greater increase when compared to the 30°s $^{-1}$ and commented that greater eccentric angular velocities lead to more muscle damage and therefore, greater hypertrophy (Table 6). Furthermore the isotonic study by Ünlü [60] showed no difference in muscle mass between 180°$\cdot$s^{-1} and 30°$\cdot$s^{-1} for quadriceps muscle volume despite each achieving 8–10s and 30–40s of TUT, respectively.

The study by Paddon-Jones [58] identified that 180°$\cdot$s^{-1} significantly increased pre to post type IIb muscle fibre values, but significantly decreased type I fibres (Table 6). The 30°$\cdot$s^{-1} training procedure caused no significant changes in any muscle fibres assessed and there was no difference between the 180 and 30°$\cdot$s^{-1} post study. Shepstone [53] (part 1) identified no difference between 210°$\cdot$s^{-1} and 20°$\cdot$s^{-1} eccentric IKD for type Ia and IIa fibre %, though, type IIx significantly decreased for both groups from pre to post. The study did identify a significant increase between the two methods for type IIa muscle fibre area % and myosin heavy chains. Additionally, both groups significantly improved from pre to post testing for myosin heavy chains type IIa fibre and both significantly decreased type IIx fibre % and myosin heavy chain (Table 6).

The review by Schoenfeld [105] further implies a distinct difference between isokinetic and isoinertial exercises as during isokinetic there is a constant resistance and is not gravity dependent. Muscle tension has been categorized as a key determinant for hypertrophy [105,118]. There will be an increase in muscular tension during faster eccentric actions as both force and velocity are enhanced, therefore, muscular tension increases [14]. Schoenfeld [117] comments that isokinetic training should be performed fast if the goal is to increase muscle mass, however, the results of our review does not show clear differences between using the measures during eccentric actions.

Research seeks to optimise training to enable the greatest result with the available resources to practitioners to elicit greater muscle mass, though, one could view that no difference between methods is a positive. First, this means methods are interchangeable. However, as there is no distinct difference between methods, <2s eccentric tempos and >180°$\cdot$s^{-1} IKD can also increase other factors such as strength, power, and SSC function, it could be argued that this method is superior because of its capacity to increase other aspects of performance. More research is needed to investigate the effects of <2s eccentric phases to determine how these impact muscle mass gains when volume is not matched with a tempo that is greater than a 2s eccentric phase.

4.6 Eccentric Velocity: What is Fast?

Categorising fast and slow movements is a construct that researchers have based on movements where comparisons are made between multiple specific velocity, torque or duration values against an action that is either faster or slower than its counterpart. However, classification of the terms fast and slow can be misleading [45–47]. Velocity-based training provides direct velocity ranges such as strength-speed (0.75 – 1.00 m$\cdot$s^{-1}) and speed-strength (1.00 – 1.3 m$\cdot$s^{-1} [13,37], avoiding use of the terms slow and fast. Table 7 demonstrates disparity within the literature as to what is classified as fast (ranging from 180-240°$\cdot$s^{-1}) and slow (20-60°$\cdot$s^{-1}) via Isokinetic Dynamometry (IKD). Further the categorisation of fast and slow is an arbitrary process as the terms refer to no set parameters [45,47]. Without such parameters, simply deeming one as fast due to its increased velocity/torque is a comparative measure and does not necessarily follow that the other values may be considered slow. This interpretation is supported by Cronin [45] who comments that utilising IKD at 60°$\cdot$s^{-1} and 240-300°$\cdot$s^{-1} (slow and fast respectively) are classified to these terms simply due to the constraints of the equipment [13,16,48].

Table 7: Isokinetic dynamometry angular velocity values across studies which employ the terms of fast and slow

Study	Training method	Classified (fast)	Classified (slow)
Shepstone [53] Roschel [54]	IKD	210° s^{-1}	20° s^{-1}
Farthing [55] Farthing [56] Paddon-Jones [57] Paddon-Jones [58]	IKD	180° s^{-1}	30° s^{-1}
Chapman [50]	IKD	210° s^{-1}	60 s^{-1}
Aagaard [59]	IKD	240 s^{-1}	60 s^{-1}
Ünlü [60]	I sotonic training	189 s^{-1}	30 s^{-1}

IKD: Isokinetic dynamometry; **$°·s^{-1}$**: Degrees per second; Note: All values were calculated to $°·s^{-1}$ for comparison, calculated via Excel with the following formula 1 $rad·s^{-1} = 57.3°·s^{-1}$.

To devise training programmes around velocity of movement a coach will typically manipulate the tempo of the different phases of an exercise. Authors highlight that movement tempos should be performed for different durations, classing these as fast and slow [14,61]. Reviews vary on the temporal definition of fast and slow tempos with some suggesting that a 1 s eccentric and 1 s concentric is fast [14,61,62]. However, Krzysztofik's review [63] defined fast as <2 s for the eccentric phase whereas [64] determined a temporal range of 2-9 s as fast for a whole repetition, they explained durations <2 s could be termed as explosive or moving as fast as possible (Table 8). These disparities within the literature confuse how movements should be defined and performed to attain desired results. Further complications in utilising phase duration to determine actions are linked to individual anthropometrics. If two participants with different lever lengths complete a movement for the same duration, the one with the greater range of motion would achieve a higher velocity, potentially achieving a different stimulus.

Ambiguities in the calculations of movement velocities such as no consideration of participant's anthropometrics coupled with the use of the terms 'fast' and 'slow' should be altered to improve accuracy in the literature. For example, when comparing training methods such as tempo training and IKD the terms of fast and slow become redundant, as they can only be termed in their specific training method and cannot be compared to other training methods. Therefore, within future research, specific values should be utilised alone. If authors wish to add tempo terms to intended durations they are advised to view research by Wilk et al [64] who incorporates exercise tempos of fast (2-4.9 s), medium (5-9.9 s) and slow (10-14.9 s) terms. With the addition of X providing maximal velocity the load can be lifted and V which determines an individual's preferred velocity during an exercise (tempo example X/1/2/1). If all future studies use the same terms of tempo training this would avoid confusion during their implementation.

Table 8: Movement tempo durations for various studies which use the term of fast and slow.

Study	Exercise	Defined as eccentric or overall tempo	Classified (fast)	Classified (slow)
Wilk [65]	Bench Press	Eccentric	Regular: 2 s	Slow: 6 s
Wilk [66]	Bench Press	Eccentric	Regular: 2 s	Slow: 6s
Calixto [67]	Bench Press	Eccentric	Fast: 0.5 s	Slow: 3 s
Douglas [43]	Back Squat	Eccentric	Fast: 1 s	Slow: 3 s
Stasinaki [68]	Back Squat	Eccentric	Fast: X	Slow: 4 s
Pereira [69]	Scott Curl	Eccentric	Fast 1 s	Slow: 4 s
Kojić [70]	Bicep curl	Eccentric	Fast: 1 s	Slow: 4 s
Wilk [71]	Bench Press	Overall	Fast 2/0/X/0,	Slow: 6/0/X/0
Lopes [72]	Bench Press	Overall	Fast: 0.75 s ECC, 0.75 s CON, (total 1.5 s)	SLOW 3 s ECC, 3 s CON, (total 6 s)

REG: Regular, **X:** Fast as possible, **S:** Seconds, **ECC:** Eccentric, **CON:** Concentric, **FAST:** Authors defined this tempo as fast within their research, **SLOW:** Authors defined this as a slow tempo within their research, **REGULAR:** Authors defined this as regular which falls in between the paradigm of fast and slow tempos.

4.7 Accelerated Eccentrics: The Resurrection

Various terms are utilised to describe an intended accelerated eccentric motion: fast eccentric, dynamic eccentrics, antagonistic facilitation specialised method (AFSM), overspeed eccentrics, accentuated eccentric loading, and accelerated eccentrics. Having no agreed operational definition limits both research and practical implementation as various terms are used in accordance with similar or the same intended training method. Verkoshansky and Siff [13] comment on implementing "accelerated powermetrics" motions during training. They termed this "accelerated eccentrics" which is sub-categorised into two groups. The first is passively accelerated eccentrics where either resistance bands are incorporated, or an external partner pushes the barbell (a method of an inverse forced repetition). The aim is to enable the bar to accelerate downwards and when the desired distance is completed the athlete will decelerate the bar and complete the concentric phase. Actively accelerated eccentrics are when an individual will perform a drop catch where the intention is to begin with limbs at extension and then to drop and catch the bar towards the end of the eccentric phase. Another form of actively accelerated eccentrics is to pull the bar down as fast as possible. Therefore, the term accelerated eccentrics would be the most applicable to utilise as it focuses on maximising the acceleration of the eccentric phase and incorporates an agreed definition to the training method reducing confusion among practitioners and researchers.

The term overspeed eccentrics originates from Louie Simmons of Westside Barbell Club who used resistance bands to increase eccentric acceleration and provide accommodating resistance. However, overspeed is a term widely used in coaching and is given to an exercise that achieves a greater velocity than is possible during normal isoinertial movements and can cause confusion as the term overspeed is used to define two differing types of training. Overspeed eccentrics as a term should not be used in accordance with assisted training where an athlete's load is decreased by attaching bands to a harness [73] or by pulling on a band during a jump [74]. The term overspeed eccentrics can still be utilised by coaches, though, caution must be applied for the term not to be used for assisted training to ensure the integrity of the term remains clear throughout literature. To the authors knowledge AFSM has not yet be referenced in the peer reviewed literature, the method originates from Triphasic training programme [75].

Resistance bands have been used during AEL to provide resistance during the eccentric phase of a countermovement jump and drop jump [76,77]. Though this method would accelerate an individual's mass faster during the eccentric phase than weighted AEL [51] with the aim to accelerate an athlete incorporating the velocity measure in the force-velocity curve [37]. Therefore, it is recommended that if bands are utilised instead of increasing mass during AEL then the term of accelerated eccentric loading (ACEL) should be employed as this give further credence to the training method. This can be seen in the band release method [40].

4.8 Accelerated Eccentric Training Methods: Current Evidence

When interpreting values from IKD, it is difficult to compare it with isoinertial movement values, which are gravity dependent [52,78]. During IKD there is an initial acceleration phase [13] followed by a period of constant torque, the purpose being to resist force during eccentric actions [79]. During isoinertial methods such as free weights, acceleration due to gravity is the only external force acting on a mass. Therefore, when performing high velocity movements during an unweighing phase (when individuals do not attempt to decelerate a movement) there is no mechanical tension being applied to the mass [78]. This is how IKD and isoinertial methods differ [80], however, once athletes decelerate the mass (braking phase) eccentric muscle lengthening occurs [78]. Additionally, during accelerated eccentric motions mass travels at a greater velocity. If two objects are the same mass and travel the same displacement, though if one has a greater acceleration, then momentum will increase, subsequently, a greater impulse (impulse = force □ Δtime) is required to stop the mass in motion [51]. This is evidenced by Van den Tillaar [81], where participants performed back squats with different eccentric execution velocities, they identified faster eccentric actions achieved the greatest force as the two faster velocities achieved a greater peak force during the lowest displacement (bottom) of a back squat [7].

A recent survey exploring eccentric training methods demonstrated that IKD is rarely implemented within training [82,83] as it has little practical application within a strength and conditioning environment and that very few have access to [80,84]. Training should replicate sporting movements [52], supporting the theory of dynamic correspondence [13,75,85,86], reinforcing that IKD is limited to angular velocity values that are not compatible with sporting motions [45]. Interestingly, the aforementioned studies highlighted tempo training is frequently employed in practice [82,83,87]. Thus, suggesting that research must provide more practical based methods such as tempo training to enable a greater impact on larger populations. Further, Paddon-Jones [58] eluded that fast and slow are incorrect terms, and that methods should specify training velocities, as specific values create different results. This implies that additional methods such as eccentric cueing or resistance banded exercises need to be understood to enable coaches to employ accelerated eccentrics more effectively.

5.0 Conclusion

We as the authors, recommend when using increased velocity eccentric actions, the term of accelerated eccentrics should be used and accelerated eccentric loading (ACEL) should be employed when the external accelerating stimulus is released at the end of the eccentric phase. This creates a distinct difference between increasing mass (AEL) or velocity (ACEL). When employing IKD the terms of fast and slow should be avoided, instead specific angular velocity values should be reported. During tempo training the term of fast or <1 s tempo should be substituted with “as fast as possible” furthermore, during tempo training specific timeframes should be employed instead of the previous fast and slow classification (Table 1).

If IKD is utilised, angular velocities of >180°s $^{-1}$ should be used over <60°s $^{-1}$ as results imply greater strength gains. There is no clear difference between <60°s^{-1} and >180°s^{-1} for hypertrophic increase. Tempo methods of <2s are superior to create greater 1RM scores and higher mean and peak concentric velocity and power. Slower tempos (>2s) result in greater accumulation of BL, growth hormone and testosterone however, this only occurs when the volume and intensity is matched. Research needs to review shorter durations with greater volume than longer ones to determine if one is superior in achieving greater muscle mass. There is no clear difference between <2 s and >4s for increases in muscle mass. This review highlights the need for more research into training with various eccentric speeds with particular focus on areas such as accelerated eccentrics and <1 s tempos to determine adaptations from these methods.

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