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The Current Knowledge and Future Direction into a New Era of Eccentric Training, A Delphi Study

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ABSTRACT

The purpose of the study was to gain a consensus surrounding specific topics concerning eccentric muscle actions and training. Twelve leading researchers and practitioners agreed to conduct the study, of which eleven completed both rounds of the Delphi study. Statements consisted of: defining eccentric training (Question 1) and eccentric overload Question 4), a new construct of time in action, and finally how would they describe an eccentric muscle action. Both a consensus was reached for eccentric training definition: Eccentric training consists of training methods that incorporate just the eccentric phase, or the manipulation of eccentric actions or training with an eccentric emphasis during resistance or plyometric-based training that have two or more contractile phases (concentric, eccentric, isometric), and a classification to muscle lengthening actions consisting of a passive lengthening action, and an active and forced eccentric action (75%). A consensus was reached of a new term of time in action describing the duration of a phase or movement (100%). Finally, a consensus was not reached for a definition of eccentric overload (64%), and that if the term is used researchers are encouraged to define eccentric overload. Future research now needs to assess these concepts on a wider population and for research to investigate some of the concepts raised from the current study.

Keywords: Consensus, Eccentric overload, Eccentric muscle action, Terminology.

INTRODUCTION

The word eccentric in the English language defines someone or a behavior that is seen as unconventional or somewhat strange (Faulkner, 2003). This resonates with the definition of eccentric muscle actions whereby the distal and/or proximal point of a muscle is lengthening. The similarity in definitions becomes apparent during muscle lengthening actions, which exhibit unconventional behaviors in comparison to concentric (muscle shortening) and isometric (muscle length remains unchanged) actions. During these lengthening actions, greater forces are achieved as velocity increases (Nuzzo et al., 2023). This is in contrast to concentric actions, where an increase in force production is accompanied with a decrease in velocity (Kellis & Baltzopoulos, 1995).

Eccentric muscle actions have also been defined as a braking/deceleration action (Handford et al., 2022, 2023); for example, muscles work eccentrically during daily life while walking downstairs or lowering objects (Harris-Love et al., 2017; Lindstedt et al., 2001). Within strength and conditioning, eccentric training now encompasses a variety of training methods such as accentuated eccentric loading (AEL), eccentric-only, flywheel inertia

training, and eccentric tempo training, to name just a few (Douglas et al., 2017a). However, these training methods yield different physical responses in relation to the loading paradigm and exercise execution (Handford et al., 2023). Though various research articles have viewed eccentric training methods as a collective (Douglas et al., 2017a; McNeill et al., 2019), or analyzed specific methods such as AEL (Wagle et al., 2017) and flywheel (Allen et al., 2021; Chaabene et al., 2022), few have compared eccentric training methods against each other. Thus, there is a lack of understanding into methods which could yield similar responses or one which may produce a greater response.

Vogt and Hoppeler (2014) described two outcomes for energy during eccentric movements: 1) energy is dissipated as heat, to decelerate an individual (Douglas et al., 2017b; Nishikawa et al., 2018; Vogt & Hoppeler, 2014), and 2) energy is conserved within the body (i.e., in the muscle's Titin filament (Nishikawa, 2016, 2012) or tendon), to prevent prolonged amortization. This stored energy is later utilized during concentric actions, facilitating a stretch-shortening cycle (SSC) motion (Nishikawa et al., 2018; Stanton & Purdam, 1989; Vogt & Hoppeler, 2014). Table 1 identifies various definitions and interpretations of eccentric muscle actions. By definition, these are all correct, yet they describe slightly different outcomes. Some describe an eccentric motion where the external force exceeds the force produced by the muscle and the muscle is then forcibly stretched, or when a muscle is lengthening. In contrast, others state that eccentric actions only occur when muscles are yielding to a force (Zatsiorsky, 2008). Given their potential as training stimuli, it is paramount to understand the current physiological theories and knowledge around eccentric muscle actions. Enhanced physical responses from eccentric training have prompted researchers to focus on optimizing this method to achieve specific outcomes. Much of this research centers on the increased force production during eccentric actions to create an overload stimulus, typically by increasing the mass However, this emphasis leaves other potentially beneficial areas under-researched. These areas could lead to unique or even greater adaptations compared to methods like AEL or eccentric-only training. One such area is the use of fast eccentric actions, which prioritizes velocity over the load lifted (Douglas et al., 2017b). This approach may yield unique adaptations that are currently unknown to researchers and coaches, making it a critical area for further investigation. Conducting research in this field is essential for a more comprehensive understanding of eccentric training

To date, eccentric muscle capacities are not well understood (Nuzzo et al., 2023) and multiple training methods encompass eccentric training, yet, there has not been a large-scale consensus from leading researchers and coaches around the intricacies of eccentric training and further, what direction eccentric training should be explored to stipulate practical knowledge for not just strength and conditioning (S&C) but physical training as a whole. The term Delphi originates from the Ancient Greek Oracle of Delphi, who could predict the future which promoted anonymity and avoided direct confrontation between experts. Today, a Delphi study is employed to establish a consensus amongst experts (Barrett & Heale, 2020), which is a requirement within the current area of eccentric training to ensure that a majority agree on specific topics. A Delphi study would progress eccentric training into a new era of research and provide specific direction of future research to provide S&C coaches important information to positively impact their practice. Therefore, the purpose of this Delphi study was to create a consensus around eccentric training and discuss specific topics that need addressing to allow eccentric training to progress.

METHODS

Study design

The Delphi method is seen as a valid protocol to create a large-scale consensus among experts regarding a topic area which requires amending or provide information into a new conceptual thought that may be accepted to aid a specific topic area (Kite et al., 2022). A Delphi considers both expert opinion and expert practical experience (Paton et al., 2023). An expert panel were invited to participate in the study. Participants would provide their opinion on specific statements which were then amended by the researcher if required, this process was repeated until the majority of participants concluded the same opinion with regards to the specific statements, thus obtaining an expert consensus.

Participants

An international representative group of multidisciplinary practitioners and researchers were invited to participate, based on their expertise

Table 1. Various definitions that have been utilised to describe an eccentric muscle action.

Eccentric definition	
Adhering to an action which is either forcibly lengthened or lengthened due to the external force	
(Schoenfeld & Grgic, 2017)	Eccentric muscle action occurs when a muscle produces force and the muscle forcibly elongates.
(Nishikawa, 2016)	Eccentric, or lengthening, contractions occur in muscles when the external force acting on them is greater than the force that they produce.
(Bridgeman et al., 2015)	Eccentric muscular action involves the lengthening of a muscle due to an external load.
(Herzog, 2018a)	When an active muscle elongates by external forces and thus absorbs work or produces negative work.
(Lindstedt et al., 2001)	Any time the magnitude of the force applied to a muscle exceeds that produced by the muscle, it will lengthen.
(Douglas et al., 2017a)	Eccentric muscle actions occur when the load applied to the muscle exceeds the force produced by the muscle itself, resulting in a lengthening action.
(Enoka, 1985)	When the muscle torque is less than the load torque, the activated muscle is lengthened and performs an eccentric contraction to lower the load.
(Prilutsky, 2008)	A muscle is acting eccentrically if it is active (i.e. produces active force as opposed to passive force, and its length is increasing in response to external forces (e.g. weight of load, force produced by other muscles, etc.).
(Hody et al., 2019; Lindstedt et al., 2001)	An eccentric (lengthening) muscle contraction occurs when a force applied to the muscle exceeds the momentary force produced by the muscle itself, resulting in the forced lengthening of the muscle-tendon system while contracting.
(Douglas et al., 2017b)	An eccentric muscle contraction refers to a muscle activity that occurs when the force applied to the muscle exceeds the momentary force produced by the muscle itself and results in a lengthening action (i.e. work is done on the muscle).
(Harris-Love et al., 2021)	The net force generated during active muscle lengthening occurs when the external resistance exceeds momentary force produced by the agonist muscle.
Vogt & Hoppeler, 2014)	Eccentric contractions are defined as muscle activities that occur when the force applied to the muscle exceeds the momentary force produced by the muscle itself. Under these conditions the activated muscle is lengthened ("lengthening contraction"). Furthermore, Eccentric contractions are generally used to decelerate or brake or to absorb energy.
(LeStayo et al., 2003)	The greatest magnitude forces in muscle occur when an external force exceeds that produced by the muscle and the muscle lengthens, producing an eccentric contraction and negative work.
(Hedayatpour & Falla, 2015)	During eccentric contractions the load on the muscle is greater than the force developed by the muscle and the muscle is stretched, producing a lengthening contraction.
(Mike et al., 2015)	An eccentric action results when the force produced inside the muscle is less than what is applied to the muscle externally and results in active lengthening of the muscle fibres under some level of load.
(Morawetz et al., 2020)	Eccentric exercise is characterized by a lengthening under tension when the load on the muscle is greater than the force exerted by the muscle. During body deceleration (e.g., downhill walking), eccentric contractions dissipate mechanical energy.
(Proske & Morgan, 2001)	During eccentric exercise the contracting muscle is forcibly lengthened.
(Harden et al., 2022)	Eccentric muscle action occur when the force generated by the muscle is less than the force imposed by the external stimulus causing the muscle to lengthen whilst active.
(Mike, 2019, 2015)	An eccentric action occurs when the muscle is forcibly lengthened or elongated.
(Guilhem et al., 2010)	Eccentric contractions occur when the load torque (i.e. resistance moment) imposed on the muscle or a group of muscles is greater than the muscle torque produced by all activated motor units (i.e. motor moment).
(Zatsiorsky, 2008)	A muscle is acting eccentrically if it is active (i.e. produces active force as opposed to passive force, see Chapter 2) and its length is increasing in response to external forces (e.g. weight of load, force produced by other muscles, etc.).
A muscle which is lengthening	
(Herzog, 2014)	Contractions in which an active muscle is stretched.
(Stauber, 1989)	A lengthening action.
(Herzog, 2018b)	A muscle is lengthening while activated.
(Cowell et al., 2012)	An eccentric muscle action is described as a muscular contraction occurring while the muscle is simultaneously lengthening.

(Roig et al., 2009)	Active lengthening of the muscle fibres.
(Roig et al., 2009)	Eccentric actions, consisting of the active lengthening of the muscle fibres.
(Manfredini Baroni et al., 2015)	Eccentric contractions are associated with muscle stretching.
Relation into SSC and how energy is stored	
Harden et al., 2022)	During tasks such as running, sprinting, and reactive jumping (i.e., stretch-shortening cycle actions), elastic potential energy is stored within the connective tissues of the muscle-tendon unit during the eccentric phase, then released and utilised during the propulsion phase, supplementing the force produced from the concentric muscle action.
Morawetz et al., 2020)	During body deceleration (e.g., downhill walking), eccentric contractions dissipate mechanical energy. Therefore, kinetic energy is converted into elastic energy of the tendons and supports the subsequent locomotion (e.g., whereas lower energy and muscle work are required in locomotion.
(McNeill et al., 2019)	During an eccentric contraction, kinetic energy is transferred and stored as elastic potential energy within the muscle tendon unit, which can acutely enhance force production in the subsequent concentric contraction through the stretch-shortening cycle.
Other comments	
Guilhem et al., 2010)	During, an isotonic eccentric contraction has a first shock-absorbing phase during which the force imposed by the load is greater than muscle force, followed by a phase during which the subject controls the load, up to the extreme angles where load control becomes more difficult.
(Suchomel et al., 2019)	Eccentric muscle actions involve the active lengthening of muscle tissue against an external force or load.
(Isner-Horobeti et al., 2013)	Eccentric muscle work muscle bears an external load and exerts braking actions. Eccentric muscle actions generate antigravity and braking movements.
(Isner-Horobeti et al., 2013)	Eccentric muscle actions generate antigravity and braking movements.
(Franchi et al., 2017)	Eccentric contractions allow the dissipation of mechanical energy during body deceleration e.g., descending stairs/walking downhill, in which the quadriceps and plantar flexors muscles generate force while lengthening, to exert a breaking action against downward movement and to maintain balance), but they also allow the conversion of kinetic energy into elastic energy of tendons.

Key: SSC: Stretch shortening cycle.

Table 2. List of participants who completed the Delphi study, (order: surname alphabetical order).

Name	Position and Affiliation
Dr Matthew J Barnes, PhD.	Associate Professor, School of Sport, Exercise & Nutrition, Massey University, New Zealand.
Dr Marco Beato, PhD.	Head of Sport and Exercise Science, Associate Professor, School of Allied Health Sciences, University of Suffolk, Ipswich, United Kingdom.
Prof Paul Comfort, PhD, CSCS*D, ASCC.	Professor of Strength and Conditioning, University of Salford, United Kingdom.
Dr Jamie Douglas, PhD.	Performance Scientist at High Performance Sport New Zealand.
Dr Ben Drury, PhD, MSc, BSc, PGCHE, FHEA, ASCC, CSCS.	Senior Lecturer and Researcher in Strength and Conditioning, Department of Sport, Hartpury University, United Kingdom.
Dr John Fernandes, PhD, PGcert, BSc.	Senior Lecturer in Sport and Exercise Sciences
Dr Martino Franchi, BSc, MRes, PhD .	Assistant Professor (Tenure-Track) at University of Padova, Padua, Italy.
Dr Kevin L de Keijzer, BSc, MSc, PhD, CSCS.	Academy Physical Performance Coach at Manchester United Women
Dr Jonathan Mike PhD, CSCS*D, NSCA-CPT*D, USAW, NKT-3.	Sports Performance Coach/Leading Industry Speaker, Owner, Scientific Strength, USA
Dr. Christopher B. Taber PhD, CSCS*D, CPSS*D, EP-C, USAW3.	Associate Professor, Sacred Heart University
Dr Michael Young, BS, MSS, PhD.	Performance Director at Athletic Lab.

surrounding eccentric training. The criteria for expert inclusion were either a combination or singular of the following: multiple publications within academic peer-reviewed journals within the realm of eccentric training, completion of a PhD focused around eccentric training, to be a coach who is known as a leader in the implementation of eccentric training, and/or still currently researching or practicing eccentric training. Twenty-five individuals met the inclusion criteria to participate in the study. Invitation emails to participate in the study were sent 07/06/2023; of the twenty-five invited participants, twelve participants agreed to take part in the Delphi study and completed round one. The final email sent that concluded the study was competed on the 26/01/2024. One participant was unable to complete round two of the study; however, their round one responses were still analyzed. Participants were provided the option to make their participation known in the current study these individuals can be seen in Table 2.

Round one

Participants were contacted in relation to taking part in the survey study. Participants completed the Delphi study via an online survey (Qualtrics software, Version [01/07/2023 – 31/12/2023] of Qualtrics. Copyright © [2023] Qualtrics. Qualtrics and all other Qualtrics product or service names are registered trademarks or trademarks of Qualtrics, Provo, UT, USA. https://www.qualtrics.com) where informed consent was completed prior to completing the questionnaire.

For round one, specific topic areas were decided to be addressed by the researcher. This was structured via five questions (Table 3). Questions one, two and three were posed with a definition that participants were asked to determine their opinion via a Likert scale or 1-10, (1 = strongly disagree, 5 = neutral, 10 strongly agree), they were also provided an option to write additional information if they felt it necessary. Question four asked participants to provide a definition for eccentric overload, and question five was answered using a yes or no response.

Round two

Following the round one responses of participants, the authors analyzed and interpreted the results and written responses. This provided vital information into how questions in round two should be formulated either amending or disregarding questions from round one. Upon this, round two was conducted to provide further clarification in relation to specific questions or outlining the chosen decision by the research team (Table 4).

Analysis

For questions one, two and three, in round one, both the Likert scale and participants comments were taken into consideration to determine if another round was required. It was determined that all three questions should reach at least 75% agreement between participants for a consensus to be reached (Christie & Barela, 2005). However, participant comments were considered to aid the development of future questions. For round two, a consensus was reached if 75% of participants agreed to the proposed statements; however, comments from participants were utilized to which the research team deemed if a consensus was reached.

RESULTS

Round one

Question one had a strong bias towards accepting the definition. However, amendments to the definition were requested by the participants resulting in a revised version being created for round two (Table 5). A consensus was not reached for question two and three which resulted in the question being amended for a further round to aim to achieve a consensus (Table 5).

Within Question four, participants were asked to provide their definition of eccentric overload with responses presented in Table 6. From these responses, a formulated question and response was then created by the authors for round two.

The results of question five, identified a large consensus in not agreeing to change the term eccentric phase, this inferred that the terminology should remain the same and no further action was required for question five.

Round two

Findings from round two demonstrated a strong bias of agreement for question one and question two however, participant comments were taken into consideration to formulate a decision. (Table 7). The research team asserted that question one reached a consensus; however, it was deemed

Table 3. Delphi round 1 question proposed to the participants with the rationale to the proposed questions.

Question	Rationale	Proposed definition	Participant response
Question 1: How would you define "eccentric training"?	There is limited terminology to define what is considered as "eccentric training".	Eccentric training consists of training methods that incorporate just the eccentric action of an exercise or aim to augment the eccentric phase during eccentric, isometric and concentric based movements in a specific manner such as altering the mass, torque, force, velocity, or duration to achieve a specific result. **Proposed definition 1.** Passive Eccentric Action: This is when the muscle is lengthening but not active and is unable to begin deceleration. **Example in practice:** This can be seen when viewing the antagonist muscle during specific movements or the unweighing phase of an exercise.	Likert scale. Written answer explaining response
Question 2: How would you describe an "eccentric muscle action"?	There are various forms of "eccentric muscle action". However, we suggest that there be three definitive forms of an eccentric muscle action.	**Proposed definition 2.** Active Eccentric Action: This is when the muscle is lengthening but is active and can decelerate and eventually prevent lengthening. In doing so the muscle can overcome the momentary force. **Example in practice:** This can be noted during resistance-based training of loads < 100% of one repetition maximum and flywheel training. **Proposed definition 3.** Pure Eccentric Action: This is when the muscle is lengthening, active and resisting the lengthening action, however, the muscle is unable to decelerate the external momentary force. **Example in practice:** This can be seen during eccentric only exercises or when performing training methods such as isokinetic dynamometer or supramaximal accentuated eccentric loading.	Likert scale. Written answer explaining response
Question 3: "Time in action" to replace "time under tension".	"Time under tension" is used in combination with the tempo of a given exercise. However, in previous studies, during negative displacement an unloading (negative displacement without muscular activity decelerating the action) occurs. Meaning the muscle is not under tension for this whole period of time.	Time in action should be the new proposed definition to replace time under tension.	Likert scale. Written answer explaining response
Question 4: How would you define "eccentric overload"?	Eccentric overload is a term that is used in combination with eccentric training to allow for an "overload" of the eccentric phase. However, there is a limited consensus to what is defined as eccentric overload	What do you define eccentric overload to be, and can you give one example of what you would consider to be an eccentric overload exercise and one example of an exercise, which you would not consider to be an eccentric overload exercise.	Written answer explaining response
Question 5: Should the terminology change for the eccentric phase on an exercise?	The downward phase of an exercise is thought to coincide with the eccentric phase of an exercise. However, as previously noted eccentric muscle actions can occur with no active deceleration (passive eccentric muscle action).	Due to these factors, should terminology be altered to reduce confusion between the eccentric phase and the muscle action and therefore, disregard or alter the term eccentric phase?	Yes or no answer. Written answer explaining response

Table 4. Round 2 questions posed to participants within the Delphi study.

Question	Rationale	Proposed outcomes presented to participants	Participant response
Question 1: How would you define "eccentric training"?	From the comments obtained from round 1 participants were provided two options for the definition of eccentric training.	Definition 1 (Original): Eccentric training consists of training methods that incorporate just the eccentric action of an exercise or aim to augment the eccentric phase during eccentric, isometric and concentric based movements in a specific manner such as altering the mass, torque, force, velocity, or duration to achieve a specific result Definition 2 (New): Eccentric training consists of training methods that incorporate just the eccentric phase, or the manipulation of eccentric actions or training with an eccentric emphasis during resistance or plyometric based training that have 2 or more contractile phases (concentric, eccentric, isometric). This is achieved by augmenting the eccentric phase of exercises altering the mass, torque, force, velocity, duration, or exercise technique (changing the number of limbs involved or exercise order i.e., a concentric deadlift into an eccentric Romanian deadlift). This is completed to provide a greater stimulus during the eccentric phase than traditional resistance-based training to achieve a specific result.	Definition 1 or definition 2
Question 2: How would you describe an "eccentric muscle	From the comments received in round 1, new definitions were formulated	Passive Eccentric Action: This is when the muscle is lengthening but not active and is unable to begin deceleration. Example in practice: This can be seen in the antagonist muscle during specific movements or the unweighing / unloading phase of an exercise (e.g., countermovement jump). Active Eccentric Action: This is when the muscle is lengthening but is active and can decelerate and eventually prevent further lengthening at a set range of motion. In doing so the muscle can overcome the momentary force. Example in practice: This can be observed during resistance-based training of loads < 100% of one repetition maximum, submaximal AEL and plyometric based training. Pure/Forced Eccentric Action: This is when the muscle is lengthening, active and resisting the lengthening action, however, the muscle is unable to decelerate the external momentary force and continues to lengthen within a set range of motion. Example in practice: This can be seen during eccentric only exercises or when performing training methods such as isokinetic dynamometer or supramaximal accentuated eccentric loading.	Written response to the definitions and were asked to refer to definition 3 as either forced or pure eccentric action.

Question 3: "Time in action" and "time under tension" proposed definitions.	From the comments received in round 1, new definitions were formulated	Our proposal Time under tension should remain as the term for use when the muscle is in tension i.e., braking and propulsion phases. We are proposing that time in action should represent the time of the gross displacement of a movement thereby adhering to tempo durations. This would aid clarity even if someone is performing the eccentric action during an unweighting phase and the muscle is not causing deceleration and is not in a state of tension to cause physical adaptations. This would provide clarity to readers and academics regarding how a movement is conducted. When calculating workloads in programming, it is the movement duration rather than how long a muscle is in tension for. Proposed definitions Time under tension: The duration when a muscle is active and able to decelerate or cause movement. Time in action: The total duration of movement from beginning to end of an exercise.	Agree or disagree with new proposed definition.
Question 4: How would you define "eccentric overload"?	From the comments formulated	One could assume to avoid confusion we begin to refer to specific training methods as opposed to that of "eccentric overload". This would be due to the fundamental principle that all eccentric training methods are "overload" or else they are isoinertial methods. This would then stop the argument of "is a training method eccentric overload" and rather view them for what they are, which is eccentric training methods. At present it would seem eccentric overload and eccentric training imply similar concepts.	1: The term eccentric overload should begin to be utilised less and rather that specific training methods are discussed, and we highlight where they aim to increase eccentric metrics through areas such as increasing mass, velocity, or force. 2: With the proposed definitions please cultivate a proposed definition of what eccentric overload is?
Question 6: Recommendations for future research	Participants were presented the opportunity to provide their opinion on future areas of research they wish to see within eccentric training.	Please provide any future research areas you wish to be developed with regards to eccentric training.	Written response if they wish to provide a response.

Table 5. Description of participant scores for questions 1, 2 and 3 during round 1.

Question	Likert score	Number of participants with associated score (n)	Consensus reached or progress to round 2.
Question 1: How would you define "eccentric training"? **Proposed definition**: "Eccentric training consists of training methods that incorporate just the eccentric action of an exercise or aim to augment the eccentric phase during eccentric, isometric and concentric based movements in a specific manner such as altering the mass, torque, force, velocity, or duration to achieve a specific result".	10 (Strongly agree) 9 8 7 6 5 (Neutral) 4 3 2 1 (Strongly disagree)	 4 participants 3 participants 3 participants 2 participants	 Due to comments raised question progressed to round 2.
Question 2: How would you describe an "eccentric muscle action"? **Proposed definition 1.** Passive Eccentric Action: This is when the muscle is lengthening but not active and is unable to begin deceleration. **Proposed definition 2.** Active Eccentric Action: This is when the muscle is lengthening but is active and can decelerate and eventually prevent lengthening. In doing so the muscle can overcome the momentary force. **Proposed definition 3.** Pure Eccentric Action: This is when the muscle is lengthening, active and resisting the lengthening action, however, the muscle is unable to decelerate the external momentary force	10 (Strongly agree) 9 8 7 6 5 (Neutral) 4 3 2 1 (Strongly disagree)	5 participants 3 participants 1 participant 1 participant 2 participants	 Due to comments raised question progressed to round 2.
Question 3: "Time in action" to replace "time under tension". **Proposed question**: Time in action should be the new proposed definition to replace time under tension.	10 (Strongly agree) 9 8 7 6 5 (Neutral) 4 3 2 1 (Strongly disagree)	1 participant 2 participants 2 participants 3 participants 2 participants 2 participants	 Due to comments raised question progressed to round 2.
Question 5: Should the terminology change for the eccentric phase on an exercise?	NA	NA	Consensus reached for term to not change.

Table 6. Question 4, written responses of definitions of eccentric overload by participants.

Eccentric overload definitions proposed by the participants
Eccentric overload can be considered when the load of the eccentric phase of the moment is above that of the concentric load used for an exercise whether this be at submaximal (i.e., eccentric load is below concentric 1RM but greater than the concentric load used) or supramaximal (i.e., eccentric load is above the concentric 1RM). Eccentric Overload Submaximal Example: An individual with a 1RM Back Squat of 100kg would use 80kg for the concentric phase (i.e., 80% 1RM) and then 90kg for the eccentric phase (i.e., 90% 1RM). Eccentric Overload Supramaximal Example: An individual with a 1RM Back Squat of 100kg would use between 105kg-140kg (depending on their maximal eccentric squat strength, if measured) for the eccentric phase. Not Eccentric Overload Exercise: Performing Tempo exercises in which the load and velocity remains similar to the concentric phase. For example, performing repetitions at 50-60% Back Squat 1RM at slow velocities of 2-6 seconds during the eccentric phase in which the load (and perhaps velocity) is the same as the concentric phase
Eccentric overload would be a stimulus large enough to drive eccentric adaptations. In practice, this would typically be a load greater than 100% of their concentric max. The best example of this would be accentuated eccentric loading with weight releasers.
I tend not to use the term eccentric overload as most productive resistance training modalities induce some form of overload as a stimulus for adaptation. I prefer the term eccentric training for training methods that load the eccentric portion of a movement at a sufficient intensity (e.g., as a percentage of maximum eccentric force) to instigate an adaptive signal specific to eccentric contractions. For example, I would consider 3 reps of a back squat executed for a controlled 3 second eccentric phase at 110% of the concentric 1RM and assisted by spotters for the concentric phase to be eccentric training. In contrast, I would not consider a back squat completed for 3 reps at 85% of the concentric 1RM without assistance to be eccentric training.
Eccentric overload represents or should represent overloading the muscle during eccentric phases of the muscle contraction. Eccentric overload refers to strength training techniques where the muscle is loaded and challenged more during the eccentric phase (lengthening phase) of movement compared to the concentric phase. The rationale for eccentric overload training is that muscles can handle up to approx 1.75 times more weight (depending on strength level or type of exercise) during the eccentric phase of the lift than the concentric phase.
Eccentric overload is a term that is used in combination with eccentric training to allow for an “overload” of the eccentric phase. This has to be demonstrated by numbers (it is a ratio). Flywheel exercise is a good example, sometimes you can have an eccentric overlord and sometimes you do not achieve that.
Taking a broad view of this, Eccentric overload is any step taken to emphasise the eccentric phase of a movement. This encompasses actions which alter the velocity of the eccentric phase (both positively and negatively), increase the loading during the eccentric phase, and increase the muscle activity. An exercise that could be considered eccentric overload is a flywheel squat, whilst a body weight squat or squat loaded <1RM (with normal tempo) would not be. The intention to specifically emphasise the eccentric phase is important here.
Eccentric overload either forces the muscle to produce greater force, eccentrically, through the use of loads greater than 100% 1RM, or extends the duration of the eccentric component of the movement by purposefully slowing the negative/lowering/deceleration phase. For example, the use of weight releasers during barbell lifts or holding the end ROM/top of a chin up for as long as possible and slowly lowering to the bottom of the ROM as gravity eventually overcomes the tension produced in the active muscles. A normal barbell or machine exercise, performed at a standard tempo, would not be considered to use eccentric overload.
In my opinion an overload is related to concept deriving from the force-velocity curve - You can overload an eccentric action based on torque/force production and subsequent activation strategies. Or one could overload the ECC phase based on power production or higher velocity of movement within similar ROM. It is clear that if one uses the term overload there should a comparison term by which the term overload can be used - I would suggest overload compared to the load that has been used/displaced in the concentric phase of the same movement. I get this is a tricky one!
The nuance comes in how eccentric overload is executed (e.g., flywheel vs AEL). Starting with overload - simply a stress or demand placed on tissue, the body, etc. Under progressive overload, we can increase this stress/demand through more resistance, repetitions, sets, frequency, intensity, or other factors. Therefore, eccentric overload may simply be applying that premise to eccentric muscle actions. In other words, stress or demand placed on a tissue using eccentric muscle actions (e.g., increased external load, volume progression, etc.).
Using a load which is greater than the maximum that can be performed during a concentric action if for example using free weights. Or when the force production is greater than the concentric force production, e.g., when using an isokinetic dynamometer. Tempo training with a load <1RM does not achieve this.

I prefer not to define it this simply because it misrepresents the somewhat already established, and very broad, definition of overload in our field. For example, overload for standard (aka concentric) strength can be achieved in a very wide range of ways as long as they a stimulus that will produce positive adaptations on a concentric capacity…. for example, you can achieve an overload using <1RM loads for more reps, more sets, more total volume, etc. I think we need to be careful not to have a definition for eccentric overload that is so rigid that it doesn't encompass all of the many ways an eccentric overload can be applied (or stimuli that produces a positive change in eccentric capacity). I think at the far range of eccentric training (AEL) this is obviously producing an eccentric overload. But for many people using the reasonably heavy loads associated with concentric strength development also produce some type of eccentric overload as long as the eccentric phase of movement is not completely passive.	
Eccentric overload is when a measurable metric (weight, power, force) is greater during the eccentric phase than the concentric phase. Example of Eccentric overload: Flywheel training where peak power is greater during the eccentric in comparison to the concentric phase. Not an example of eccentric Overload: Athlete performing a slow eccentric phase where the tempo/ time under tension is longer in the eccentric than concentric phase.	

Key: AEL: Accentuated eccentric loading, ECC: Eccentric, kg: Kilogram, ROM: Range of motion, vs: Versus, 1RM: One repetition maximum, %: Percent.

Table 7. Responses of round 2 questions from participants.

Question	Response	Additional responses
Question 1: How would you define "eccentric training"? Definition 1 (Original): Eccentric training consists of training methods that incorporate just the eccentric action of an exercise or aim to augment the eccentric phase during eccentric, isometric and concentric based movements in a specific manner such as altering the mass, torque, force, velocity, or duration to achieve a specific result Definition 2 (New): Eccentric training consists of training methods that incorporate just the eccentric phase, or the manipulation of eccentric actions or training with an eccentric emphasis during resistance or plyometric based training that have 2 or more contractile phases (concentric, eccentric, isometric). This is achieved by augmenting the eccentric phase of exercises altering the mass, torque, force, velocity, duration, or exercise technique (changing the number of limbs involved or exercise order i.e., a concentric deadlift into an eccentric Romanian deadlift). This is completed to provide a greater stimulus during the eccentric phase than traditional resistance-based training to achieve a specific result.	3 agree definition 1. 8 agree definition 2.	Individuals who selected definition 1 commented that although they agreed with definition 2, it was too long in length.

Question 2: How would you describe an "eccentric muscle action"? **Passive Eccentric Action:** This is when the muscle is lengthening but not active and is unable to begin deceleration. **Active Eccentric Action:** This is when the muscle is lengthening but is active and can decelerate and eventually prevent further lengthening at a set range of motion. In doing so the muscle can overcome the momentary force. **Pure/Forced Eccentric Action:** This is when the muscle is lengthening, active and resisting the lengthening action, however, the muscle is unable to decelerate the external momentary force and continues to lengthen within a set range of motion.	**Agreed or disagree with proposed definition** 8 agreed. 3 commented that they felt disagreed with the definitions with specific comments. **Pure or forced eccentric action?** 11 agree forced. 0 agree pure eccentric.	"If it is passive, is it really eccentric. Based on this definition stretching would be classed as an eccentric muscle action, and therefore a mode of eccentric training, which seems ridiculous. Personally, I feel that such a definition would only add to the confusion regarding eccentric actions and therefore eccentric training". "A passive eccentric action isn't an action or contraction, it's just an inactive muscle or group of muscles. I also don't think the delineation between active and pure/forces is valid, at a contractile level it's probably the same collection of mechanisms, it's just a difference in loading intensity which manifests in a particular external outcome on a velocity continuum". "The active eccentric/pure forced eccentric can both be used. Depends on the load, and intent of the exercises and /or modalities"
Question 3: "Time in action" and "time under tension" proposed definitions. **Our proposal:** Time under tension should remain as the term for use when the muscle is in tension i.e., braking and propulsion phases. We are proposing that time in action should represent the time of the gross displacement of a movement thereby adhering to tempo durations.	11 agree. 0 disagree.	NA
Question 4: How would you define "eccentric overload"? **1:** The term eccentric overload should begin to be utilised less and rather that specific training methods are discussed, and we highlight where they aim to increase eccentric metrics through areas such as increasing mass, velocity, or force. **2:** With the proposed definitions please cultivate a proposed definition of what eccentric overload is?	7 agree not use the term eccentric overload. 4 agree the term should remain.	"An eccentric overload is any training stimulus which will produce a positive adaptation on the eccentric force generating capacities of a muscle including but not limited to force generation or power output". "This should be a load that is greater than can be achieved during a concentric muscle action and therefore, greater than the eccentric stimulus during normal isotonic exercises". "Eccentric overload requires training which that allows for the specific development of the eccentric abilities such as strength, velocity, and power." "I think it's not bad to use the term eccentric overload AS LONG AS it's discussed what overload means and how it is achieved by different modalities of training".
Question 5	NA	NA

Question 6: Recommendations for future research.	"Varying means and methods of flywheel training to enhance eccentric capacities. Determining if there is a threshold limit or a point of diminishing returns for the benefits of AEL training.... for example, is the use of 130% concentric maximum always superior to 110% but inferior to 150% and are these improvements load and velocity specific". "Combined analysis of kinetics, kinematics, and EMG during multi-joint exercises, along with determining is such training modalities result in greater adaptations in performance compared to 'traditional' training approaches. Some mechanistic work, determining the cause of these adaptations is also required to better inform training prescription". "The eccentric metrics taken from CMJ testing and what this means for programming. Ultimately, I'd say at this current time that research on eccentric training methods is perhaps more advanced than the testing methods so perhaps we need to come back a stage". "The effects of eccentric training on mechanistic outcomes of interest in a more rigorous manner (e.g., muscle architecture, muscle fibre composition, muscle-tendon unit structural protein expression, neural activation etc) that can then better explain potential changes in mechanical function and performance often observed in research Additionally as well as teasing out the velocity effects further delineation of the effects of relative intensity (e.g., as % of ECC MVC, or % of CONC 1RM) on the above mechanistic and mechanical outcomes would be valuable. I feel like we are still only at the beginning of determining best practice in this space". "Some longer-term studies need to be conducted on eccentric training and responses. More training studies should be completed on these specific means for athletes and general population". "From the comments here there isn't a consensus regarding eccentric overload. I wonder whether a comparison of some of the methods noted in the comments would be useful, in terms of what adaptations they'd yield. I'd guess that while we feel/think that these (sometimes) minute differences could cause significant differences in adaptation they might actual not. From my own perspective, looking at the recovery profile and EIMD invoked from these would be really useful". "Specifically, a greater appreciation and discussion of how variety in training devices, their reliability, and how they can vary in application. For example, in flywheel training studies, we rarely consider the differences between devices in terms of shaft length, disc size (diameter, etc.), rope/tether quality/material, and the attachments that are used (size of vest, material). How software and data is processed". "Surely Isoinertial/Flywheel training. A lot of approximative research out on the topic, we need better studies describing WHY and HOW this can work from a muscle physiology perspective."

Key: AEL: Accentuated eccentric loading, CMJ: Countermovement jump, CONC: Concentric, ECC: Eccentric, EMD: Eccentric muscle damage, EMG: Electromyography, MVC: Maximal voluntary contraction, NA: Not applicable, 1RM: One repetition maximum, %: Percent,

that question two did not from the comments raised (Table 7). All participants agreed to question three so a consensus was reached, whereas for question four, a consensus was not reached to agree avoid using the term eccentric overload and rather use the name of the training method. Presented in (Table 7) are the written responses of participants for future areas of research.

DISCUSSION

Question one: Terminology of eccentric training

To the authors knowledge, an agreed eccentric training definition has not been confirmed, as such the Delphi sought to determine this. From definition one round one, comments were made in conjunction with adding or removing information from the proposed definition. In round two, though most participants commented (eight out of eleven) definition two provided more information, some commented about the length of the definition (Table 7). As such, the lead author suggests the following: Definition two refers to the full definition of eccentric training; however, a condensed version is presented which addresses the comments made by the participants.

Eccentric training definition (one): Eccentric training consists of training methods that incorporate just the eccentric phase, or the manipulation of eccentric actions or training with an eccentric emphasis during resistance or plyometric based training that have two or more contractile phases (concentric, eccentric, isometric). This is achieved by augmenting the eccentric phase of exercises altering the mass, torque, force, velocity, duration, or exercise technique (changing the number of limbs involved or exercise order (i.e., a concentric deadlift into an eccentric stiff-legged deadlift). This is completed to provide a greater stimulus during the eccentric phase than traditional resistance-based training to achieve a specific result.

Condensed eccentric training definition (two): Eccentric training consists of training methods that incorporate just the eccentric phase, or the manipulation of eccentric actions or training with an eccentric emphasis during resistance or plyometric-based training that have two or more contractile phases (concentric, eccentric, isometric).

Question two: Terminology of eccentric muscle lengthening

The current findings suggest that various training outcomes can occur during muscle lengthening depending on specific movement execution and intensity the muscle is subjected to. Though the Delphi reached the adequate threshold for a consensus (Table 7), the research team deemed it necessary for further deliberation to be conducted and an agreement with a larger sample size. Subsequently, the current study proposes the following: the new understanding from the Delphi aims to illuminate the lack of understanding into muscle lengthening and describes how the definition of an eccentric muscle action is not a one size fits all approach (Table 1). One should note that the difference between active and forced eccentric is simply the divide between an action whereby one is unable to completely decelerate or where one is able to, respectively. Furthermore, for this area to develop a greater understanding into physiological occurrences need to be established before a definitive conclusion is made. An analysis into this understanding and definitions of the proposed actions are as follows:

Passive lengthening action: This is when the muscle is lengthening but not active and is unable to begin deceleration.

Example in practice: This can be seen in the antagonist muscle during specific movements or the unweighing/unloading phase of an exercise (e.g., CMJ).

Active eccentric action: This is when the muscle is lengthening but is active and can decelerate and eventually prevent further lengthening at a set range of motion. In doing so the muscle can overcome the momentary force.

Example in practice: This can be observed during resistance-based training of loads < 100% of one repetition maximum, submaximal AEL and plyometric based training.

Forced eccentric action: This is when the muscle is lengthening, active and resisting the lengthening action; however, the muscle is unable to decelerate the external momentary force and continues to lengthen within a set range of motion.

Example in practice: This can be seen during eccentric-only exercises or when performing

training methods such as IKD or supramaximal AEL.

Passive muscle lengthening: Unloading, not resisting, not causing deceleration

During human movement, eccentric muscle lengthening occurs when the muscle increases in length, but movements can also take place with little to no resistance to decelerate the action (passive action) (Table 4) (Prilutsky, 2008). This understanding is interpreted with antagonist muscles where during movements the agonist is the contraction muscle (concentric action) causing acceleration. Whereas, the antagonist muscle relaxes (to a certain degree) allowing actions to occur (Marsden et al., 1981) when the antagonist activates causing a deceleration (eccentric action) (Jaric et al., 1999). This is noted where during ballistic and other rapid movements the antagonist contraction is appropriate only to terminate the motion of the limb (decelerate and stop) (Zatsiorsky, 2008).

The aforementioned understanding is shown in the study of Jarić et al. (1995) who discussed an increase in antagonistic strength in a shorter timeframe could be applied to decelerate the limb in motion, resulting in an increase in acceleration (agonist), thus adhering to the impulse-momentum relationship (Schilling et al., 2008). This analogy was also noted by Abbott et al. (1952) that throughout the extension muscles are actually contracting, whereas the antagonist extensor muscles which, during rapid flexion of a limb, are stretched passively for the greater part of the movement and are not excited to activity until towards the end when they cause deceleration. Marsden et al. (1981) indicated that the agonist will produce a force to create an impulse to create movement during “fast actions” while the antagonist relaxes allowing this to occur. If agonist and antagonist muscle groups were contracting, they would act as a decelerator to the other; this phenomenon is known as coactivation (Aagaard et al., 2000; Bazzucchi et al., 2006; Latash, 2018). Therefore, the antagonist (eccentric acting muscle) must either relax or create little resistance to allow movement to occur (Zatsiorsky, 2008).

The above is supported when analyzing the unweighting phase of a CMJ. Once a person begins to negatively displace (downward movement), the body will accelerate increasing downward velocity (McMahon et al., 2018). Because there is minimal to no deceleration occurring (Kopper et al., 2014), one can assume eccentric braking is not occurring and the muscle is not forcibly lengthening (i.e., forced eccentric action). This unweighting phase can be seen in eccentric training methods such as AEL (Suchomel et al., 2024) and jumping based movements (CMJ) (Bright et al., 2024). This is key for the reader to understand that not all eccentric training methods involve the pre termed pure / true eccentric action (forced eccentric action) depending on exercise execution.

Active eccentric action: Ability to overcome and decelerate

One common issue pertaining to eccentric action definitions is though the muscle is lengthening, it possesses the ability to decelerate and stop lengthening to then perform an isometric action. The information provided by Vogt and Hoppleler (2014) suggests that the muscle primarily stores elastic energy within the tendon and the actin filament Titin, as well as energy being dissipated as heat. Further, if force is not excessive, one can cause deceleration (Vogt & Hoppeler, 2014). Subsequently, if a larger enough braking force is applied, the eccentric action can overcome and decelerate the body in motion, thus acting through an active eccentric action. Additionally, energy could also be lost as a result of potential energy transferring into kinetic energy (movement); this is noted as a muscle which increases in length (Zatsiorsky, 2008). Yet, to the authors’ knowledge, there is a lack of understanding into how a muscle goes from an eccentric to an isometric action, and as such, further research is warranted.

Forced eccentric to breakpoint

The terminology researchers and coaches associate with eccentric muscle actions is when external force is greater than that produced by the muscle and subsequently it forcibly lengthens (i.e., forced eccentric action) (Lindstedt et al., 2001). During supramaximal AEL and the Nordic hamstring exercise, and eccentric-only, an understanding into how the eccentric muscle actions aim to assist the movement must be understood. During muscle lengthening actions, greater forces can be achieved compared to concentric and isometric actions (Douglas et al., 2017a; Wagle et al., 2017), and this can be achieved with increasing velocity. However, a complete deceleration would be unlikely to occur during this phase, and this is therefore termed as a pure eccentric action (Vogt & Hoppeler, 2014) or true eccentric action (Cuthbert et al., 2020). However, it should be noted that the current study

findings suggest this should be termed "forced eccentric action".

It must be noted that a maximal eccentric muscle action would be producing a force to resist the muscle from lengthening; however, a supramaximal action would explain past the point of maximal and thus, a person would likely be in a state of freefalling. Cuthbert et al. (2020) describe this during a Nordic hamstring exercise as a breakpoint angle (the angle at which the hamstrings inhibit, and the upper body falls to the floor). The individual gets closer to the ground before falling which in turn increases the torque due to force being applied over a greater moment (da Rocha et al., 2022).

Tendon and muscle action

A construct that must be brought to the reader's attention is the research of Van Hooren and Bosch (2017a) who highlighted that during sprinting motions (specifically the swing phase), it could be argued that an "eccentric muscle action" does not occur. This is built on the foundation the tendon may be lengthening but not the muscle by either performing a concentric or isometric action. The current study further concurs with regards Table 1 whereby, some participants commented about eccentric being just the muscle or the muscle tendon complex. Part II of Van Hooren and Bosch's review (2017b) further questions whether exercises like the Nordic hamstring exercise truly involve eccentric actions, as they argue it may not actually result in a lengthening of the muscle fascicles (Van Hooren & Bosch, 2017b). This understanding can be further reinforced with Handford et al. (2023) who concluded that although an individual is performing an eccentric motion, it may not be correct to assume that an eccentric muscle action is occurring. Zatsiorsky and Prilutsky (2012) further comment that during some movements though the muscle-tendon unit is stretching the muscle fascicles may be constant or shortening inferring this should not be defined as eccentric. Furthermore, they comment that a distinction between forcibly stretching the muscle-tendon unit as a whole or just the muscle belly must be noted.

Question three: Time under tension and time in action

From the information gained from question two outlining that during muscle lengthening a passive lengthening action can occur and would unlikely cause no physical adaptation it was deemed necessary that the term time under tension (TUT), which is usually associated with tempo training durations, may need amending. Initially, it was suggested that time in action (TIA) should replace TUT (Table 3). However, participants in round one commented that TUT was a term that has been used in literature and practice for a long period, and renaming and disregarding the term may create confusion (Table 5). As such, round two suggested clear definition of TUT and TIA, to which all participants agreed with (eleven out of eleven) (Table 4). The definitions are as follows.

Time under tension: The duration when a muscle is active and able to decelerate or cause movement.

Time in action: The total duration of movement from beginning to end of an exercise (Table 7).

Question four: Definition of eccentric overload

For round one participants were asked to provide their definition of what eccentric overload is (Table 6). The results demonstrated a wide range of responses with differing definitions. While it might be possible to develop a definition from these responses, the research team recommended against using the term in future research due to significant variations in the interpretation of what constitutes eccentric overload (Table 6). As such, participants were provided the option to either provide their own definition of eccentric overload or suggest that the term should no longer be used, and instead specific training methods should replace it (Table 4). Seven out of eleven agreed to using the names of eccentric training methods rather than eccentric overload (Table 7). This was not enough to warrant a consensus; thus, it is suggested by the research team that eccentric overload should not be disregarded, but rather training method names should begin to be implemented more and not just referred to as eccentric overload. If authors use the term eccentric overload, it is suggested that they subsequently define what accounts to eccentric overload. The definitions proposed by the participants (Table 7) can be used to aid in this while future research can use the information to formulate a definition of eccentric overload.

Question five: Eccentric phase terminology

Question five posed that the term 'eccentric phase' should be amended to a new definition. This was suggested as such a movement would likely occur from a passive lengthening (unweighting)

before eccentric braking occurs; subsequently, the eccentric phase would not be that purely of an eccentric braking action. Participants commented that they felt this was a valid opinion and it was deemed unnecessary to change the definition. This was mainly formulated from the eccentric phase being rooted in literature and practice; thus, changing the term would create confusion. However, it should be noted to the reader as outlined by Handford et al. (Handford et al., 2023) that just because the eccentric phase is being completed, a forced/active eccentric motion may not be occurring but rather passive lengthening. As such, the intended adaptations associated with active and forced eccentric muscle lengthening may not occur.

Question 6: Future recommendations

For question six (round two), participants were provided the option to state what future research they feel would advance the area of eccentric training (Table 4). As can be seen in Table 7, respondents identified several key areas of interest regarding eccentric training. They highlighted the need to differentiate the effects of AEL and flywheel training on various physical metrics. They emphasized the importance of kinetic, kinematic, and electromyographic (EMG) analyzes in understanding multi-joint movements during eccentric exercises. Respondents also called for mechanistic studies to uncover the factors driving specific adaptations associated with these training methods. Furthermore, they stressed the significance of exploring how variations in eccentric testing metrics can impact physical performance. The long-term effects of eccentric training, particularly on muscle architecture, were noted as an essential area for further research. Finally, the study underscored the importance of examining recovery processes and the extent of muscle damage related to eccentric training methods. One participant commented that "I feel like we are still only at the beginning of determining best practice in this space." The authors agree with this statement and suggest that eccentric training has various areas which need further investigation. In doing so, greater understanding and rationale into utilizing eccentric training will be known.

CONCLUSION

The current study provides a definition for eccentric training that can be used for future research and practice. It further provides detailed information into muscle lengthening, suggesting new terminology of passive lengthening, active lengthening, and forced eccentric actions whereby, the muscle can either decelerate and overcome the eccentric action or where the force is too great and the muscle is unable to decelerate and stop the motion, respectively. We propose a new term of TIA which provides greater clarity to movement duration whereas TUT refers to the duration when a muscle is active and able to decelerate or cause movement. Further, the term eccentric overload should be used less and substituted with the name of specific eccentric training methods. If the term eccentric overload is used, a clear definition as to what qualifies as an overload should be included.

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DATA AVAILABILITY STATEMENT

Data is available from the author on reasonable request.

CONFLICTS OF INTEREST

No potential conflict of interest reported by the author(s).

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