

1 **Four weeks of augmented eccentric loading using a novel leg press device improved leg**  
2 **strength in well-trained athletes and professional sprint track cyclists**

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14 **Short title:** Augmented eccentric loading and leg strength

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## Abstract

23  
24 This study assessed the efficacy of strength training using augmented eccentric loading to  
25 provoke increases in leg strength in well-trained athletes, and sprint track cyclists, using a novel  
26 leg press device. Twelve well-trained athletes were randomly allocated traditional resistance  
27 training (TRAD, n = 6), or resistance training using augmented eccentric loading (AEL, n = 6).  
28 A further 5 full-time, professional sprint track cyclists from a senior national squad programme  
29 also trained with augmented eccentric loading (AEL-ATH) alongside their usual sport-specific  
30 training. Participants completed four weeks of twice-weekly resistance training using the leg  
31 press exercise. In TRAD the lowering phase of the lift was set relative to concentric strength.  
32 In AEL and AEL-ATH the lowering phase was individualised to eccentric strength. Concentric,  
33 eccentric, isometric and coupled eccentric-concentric leg press strength, and back squat 1  
34 repetition maximum (1RM), were assessed pre- and post-training. The AEL and AEL-ATH  
35 groups performed the eccentric phase with an average  $26 \pm 4\%$  greater load across the  
36 programme. All groups experienced increases in concentric (5%, 7% and 3% for TRAD, AEL  
37 & AEL-ATH respectively), eccentric (7%, 11% and 6% for TRAD, AEL & AEL-ATH  
38 respectively), and squat 1RM (all  $p < 0.05$ ), where the AEL-ATH group experienced relatively  
39 greater increases (13% vs. 5% in TRAD and AEL,  $p < 0.01$ ). The TRAD and AEL groups also  
40 increased isometric strength ( $p < 0.05$ ). A four-week period of augmented eccentric loading  
41 increased leg strength in well-trained athletes and track cyclists. The eccentric leg press  
42 stimulus was well-tolerated, supporting the inclusion of such training in the preparation  
43 programmes of athletes.

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45 Key words. Resistance training; athletes; concentric; isometric; force

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## Introduction

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Muscular strength is a major contributing factor to athletic performance [1]. Greater muscular strength is associated with enhanced movement performance [2] and a decreased risk of injury [3] and as such appropriate resistance training to increase strength qualities is a cornerstone of athletic preparation programmes across a wide range of sports [4]. Conventional resistance training exercises, such as the squat and deadlift, are efficacious in improving muscular strength, however they are limited by the amount of mass the athlete is able to lift in the concentric phase. Conversely, humans are able to produce greater magnitudes of force during eccentric movements [5], and training strategies that afford an overload of eccentric muscle actions are potentially more efficacious than traditional resistance training [6-8], particularly for athletes with a long training history who might be limited in their potential to adapt to traditional resistance training methods [9-11]. The potential novelty offered by eccentric training strategies, coupled with the potential to elicit higher muscular forces than traditional training, makes such approaches attractive to well-trained athletic populations.

The application of high-intensity eccentric training is efficacious at improving strength, likely to a greater extent than concentric training as first demonstrated by Bradenburg & Docherty [12], however few studies have adopted an ecologically valid training approach. Following habitual use of high-intensity eccentric exercise there is evidence of increased maximum force producing capacity during eccentric, concentric and isometric exertions [6, 13], and numerous studies support the superiority of eccentric vs concentric training in eliciting improvements in measures of strength [6, 8, 13-15]. The majority of these studies employed isokinetic and/or single joint eccentric exercise, whereas in practice athletes typically perform multi-joint, compound movements. Two studies have demonstrated the superiority of eccentric resistance training regimes utilising augmented eccentric loading (AEL, where the load for the eccentric

72 phase is >100% of concentric strength) for increasing strength in compound movements with  
73 well-trained athletes [16, 17]. Compared to traditional training, Cook *et al.* [16] observed  
74 greater improvements in upper and lower body strength, and vertical jump performance, and  
75 Douglas *et al.* [17] reported greater increases in lower body strength and sprint speed, after  
76 eccentric training. Furthermore, Coratella & Schena [11] showed that the improvements in  
77 strength elicited by AEL are maintained after a period of detraining, whereas those from  
78 traditional resistance training were not. These data indicate that the development of  
79 ecologically valid training regimes utilising high-intensity eccentric muscle actions could be  
80 more efficacious than traditional “concentric limited” resistance training in provoking  
81 adaptation to a range of athletic performance measures.

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83 Although promising in application, there are significant logistical challenges associated with  
84 overloading the eccentric phase of resistance training movements. To this end, we have  
85 developed a novel leg press device capable of overloading eccentric muscle action in a lower  
86 body, bilateral, multi-joint movement [18, 19]. Our previous work has established the  
87 reliability of this stimulus [18], and its mechanical characteristics [19], as a foundation on  
88 which to prescribe training. The features of the device also allow the measurement of maximal  
89 concentric and eccentric strength, and thus training can be specifically prescribed relative to  
90 muscle action type, rather than prescribed to concentric strength [16, 17]. Such an approach is  
91 beneficial, particularly in highly strength trained athletes, in order to ensure task-specificity  
92 and account for potential individual differences in tolerance to eccentric exercise. The aim of  
93 this study was to ascertain the feasibility and efficacy of strength training with a novel leg press  
94 device that affords an overload of the eccentric phase on muscle function in well strength-  
95 trained individuals and in a group of professional sprint track cyclists when incorporating this  
96 approach to strength training alongside sport-specific training. Study of a group of professional,

97 full-time, sprint track cyclists enabled us to quantify the feasibility and efficacy of a novel AEL  
98 stimulus in a group of highly-trained, professional athletes.

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## Methods

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### Design

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A randomised, positive control trial was employed to test the efficacy of eccentric leg press

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training. Seventeen participants were recruited and allocated to 3 groups to complete traditional

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resistance training (TRAD, who acted as an active control group) [20] or augmented eccentric

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loading (AEL and AEL-ATH) performed on a bespoke incline leg press twice per week, for

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four weeks [18]. All groups performed leg-press exercise using a coupled eccentric-concentric

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movement with a five seconds tempo for the eccentric phase, and with maximum intent

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throughout the concentric phase. The difference between the groups was in the loading

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parameters for the eccentric phase; the TRAD group performed the descending phase with the

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same load as the ascending phase, which was prescribed based on concentric-only strength; the

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AEL and AEL-ATH groups performed the descending phase at an intensity relative to their

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eccentric-strength, and the ascending phase relative to their concentric strength, thereby

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offering an overload of the eccentric movement. The AEL-ATH group comprised full-time

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professional sprint track cyclists (AEL-ATH) from the Team GB senior academy programme

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(one level below the senior Olympic programme), to allow an assessment of the feasibility of

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the training stimulus in a professional, near-elite population. The training was preceded by two

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separate assessment sessions to measure individual strength profiles in back squat (day 1) and

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leg press exercise (day 2), The first pre-test session included familiarisation to the leg press

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machine and the tempo required for the eccentric phase. Participants were already habituated

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to traditional leg press and squat exercise from their own training. The two pre-test sessions

121 were separated by 3 days. The two assessment sessions were repeated post-training separated  
122 by 3 days, after a 7-day deload. During the post-session testing period, the AEL-ATH group  
123 were subject to an unplanned, acute increase in their training load prior to their second  
124 assessment day, which meant one strength test could not be completed because of residual  
125 fatigue (traditional 1 repetition maximum leg press assessment, described below).

126

## 127 **Participants**

128 Seventeen participants, twelve males and five females, gave written informed consent to  
129 participate in the study, which was approved by the Northumbria University Faculty of Health  
130 & Life Sciences Ethics Committee. Participant characteristics are presented in Table 1. Twelve  
131 participants were from a strength-power sport background (weightlifting, rugby, athletics,  
132 gymnastics, and combat), with 3-10 years of heavy resistance training experience; they were  
133 matched for 3 repetition maximum squat strength relative to body mass (3RM), and randomly  
134 allocated into two groups (AEL (n = 6; 1 female and 5 male) and TRAD (n = 6; 2 female and  
135 4 male). The participants in the TRAD and AEL group were strength-trained, but not full-time  
136 professional athletes. The participants in the AEL-ATH group were full-time professional track  
137 sprint cycling athletes (n = 5; 2 female and 3 male). For the duration of the study, the AEL and  
138 TRAD groups were asked to avoid any lower body resistance training activity outside of the  
139 prescribed exercise programme and avoid unaccustomed resistance and cardiovascular  
140 exercise throughout the study duration. The participants in the AEL and TRAD groups  
141 continued to practice their sport two to three times per week at a moderate intensity and  
142 confirmed that they were not scheduled to compete or perform at high or maximal intensity  
143 within the study period. The AEL-ATH group continued with their on-bike track sprint cycling  
144 full-time training programme.

145

146 **Table 1. Participant characteristics at baseline for each training group. Values are mean**  
147 **± SD.**

Group	<i>n</i>	Age (Yrs)	Stature (cm)	Mass (kg)
AEL-ATH	5	19 ± 0	174 ± 13	76 ± 12
AEL	6	28 ± 2	179 ± 7	82 ± 9
TRAD	6	26 ± 5	177 ± 7	77 ± 9

148

## 149 **Procedures**

### 150 **Strength profiling**

151 Strength was measured in leg press exercise (isometric, concentric, eccentric), and with a  
152 traditional back squat three repetition maximum. The bespoke leg press has been previously  
153 described [18, 19]. Briefly, the machine offers an overload of eccentric function via pneumatic  
154 technology, which can be immediately “unloaded” for the concentric phase of movement via  
155 adjustable magnetically operated reed switches. Force was measured via 4 s-type load cells  
156 (300 kg limit per cell) mounted onto the foot plates, which fed into a combinator to create a  
157 single voltage output. Associated with each load cell was a potentiometer (Hybritron®,  
158 3541H1-102-L, Bourns, Mexico). The load cells and potentiometers sampled at 200 Hz. The  
159 voltage from the load cells and potentiometers were relayed into data acquisition software  
160 (LabVIEW 6.1 with NI-DAQ 6.9.2, National Instruments Corporation, USA) on a desktop PC.  
161 Force-time traces for each force plate (left and right) and displacement- and velocity-time  
162 traces for each potentiometer (left and right) were displayed. Raw data was exported from the  
163 data acquisition software into Microsoft Excel format (Microsoft Excel, 2010) and were  
164 analyzed offline.

165

166 **Isometric Force Assessment (ISO<sub>90</sub>)**. To determine maximum isometric force output, the leg  
167 press foot carriage was secured to ensure the required knee joint angle (90°, verified by  
168 goniometry). The 90° joint angle was chosen as it is commonly used for isometric assessment  
169 [21, 22]. Additionally, the 90° angle reflects the angle at the end range of motion (ROM)  
170 common to coupled eccentric-concentric exercise. Ratchet straps (>600 kg limit) were used to  
171 fix the carriage firmly in place to prevent unwanted movement and to maintain the integrity of  
172 knee and hip joint angle. Two preparatory efforts were performed at 50% and 75% perceived  
173 effort, separated by 30 seconds. Testing consisted of three 5 s maximal efforts interspersed by  
174 three minutes. During each effort, participants were instructed to ‘progressively build up force  
175 towards pushing as hard as possible until instructed to stop’. The same strong verbal  
176 encouragement was provided for all efforts. Unilateral force measures were summed to reflect  
177 the bilateral nature of the exercise. The trial with the highest peak force was used for analysis.  
178 Reproducibility has been established previously [18]; intraclass correlation coefficient (ICC):  
179 0.92; coefficient of variation (CV: 3.4%); smallest worthwhile change (SWC): 3.3%.

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181 **Traditional repetition maximum assessment (TRAD<sub>1RM</sub>)**. This assessment determined the  
182 maximum weight that could be moved through an initial lowering (eccentric) then lifting  
183 (concentric) phase to the nearest 5 kg for a single repetition. This was established within five  
184 attempts, separated by five minutes. The range of motion (ROM) was standardised to 90° of  
185 knee flexion. If full ROM was not achieved, then the effort was deemed a failed repetition. The  
186 maximum load lifted was recorded for analysis. Reproducibility of the measurement has been  
187 established previously; ICC: 0.98; CV: 2.2%; SWC: 3.25%.

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189 **Maximum concentric force assessment (CON<sub>1RM</sub>)**. This assessment established the  
190 maximum force that could be produced during a concentric only movement. Participants



191 performed efforts from a “dead” push at a knee joint angle of 90° with 5 minutes separating  
192 maximum attempts. The load was adjusted in 5 kg increments, and all participants achieved  
193 their maximum within 5 attempts. Training intensities for the concentric phase were based on  
194 CON<sub>1RM</sub>. The maximum force recorded during participants heaviest load lifted was recorded  
195 for analysis.

196

197 **Maximum Eccentric Force Assessment (ECC<sub>1RM</sub>).** This assessment determined the  
198 maximum force that could be imposed on the participant which could be controlled throughout  
199 the ROM of the descending phase of the leg press exercise for a duration of five seconds. The  
200 concentric phase was loaded with 50% of TRAD<sub>1RM</sub>. To standardise the pace of the eccentric  
201 phase, a custom-built LED strip with individually addressable LEDs (WS2812, BTF Lighting  
202 Technology Co. Ltd) controlled by a development board (Elegoo Mega 2560 R3, Elegoo Inc.  
203 UK & Arduino 1.8.4) and custom written code was added to the instrument. The LEDs lit up  
204 in a gradual manner to create a light trail that the participant followed, using a marker secured  
205 to the foot carriage. The length of the light trail (total number of LED lights) was pre-set to a  
206 distance that reflected the displacement of the foot carriage to a knee angle of 90° angle. The  
207 first eccentric effort was performed with a load which was equivalent to TRAD<sub>1RM</sub>. Load was  
208 increased by 5% until the five seconds pace set by the LED lights could no longer be  
209 maintained. Five minutes rest was prescribed between attempts. Following a failed effort  
210 subjects were given one further attempt at the load. In the event of a second failed attempt,  
211 force output associated with the preceding effort was used for analysis. Maximum force was  
212 recorded for analysis, which was achieved within six efforts for all participants.  
213 Reproducibility of the measurement has been established previously [18]; ICC: 0.93; CV:  
214 3.0%; SWC: 2.9%.

215

216 **Squat three repetition maximum (SQ<sub>3RM</sub>)**. The maximum load that participants could  
217 complete 3, high bar back squat repetitions was recorded and used to prescribe subsequent  
218 training. The procedures to attain SQ<sub>3RM</sub> followed a previously established protocol, yielding  
219 reproducible results (CV = 2.1%) for strength-trained individuals [23]. Participants squatted to  
220 full knee flexion, or where this was not possible to a depth where the femur was at least parallel  
221 to the floor. Pins were set in the squat rack corresponding to the barbell height achieved at the  
222 bottom of the squat to ensure consistent depth was achieved; this was visually confirmed by  
223 the lead investigator for each repetition. Participants lowered the load under control  
224 (approximately 3 s eccentric phase) and were instructed to immediately reverse the movement  
225 and perform the concentric phase as fast as possible. Participants completed sub-maximal  
226 warm-up repetitions until a load equating to 85% of predicted 1RM. Subsequently SQ<sub>3RM</sub> was  
227 established in a maximum of five attempts, with five minutes rest permitted between efforts.

228

## 229 **Training intervention**

230 An overview of the training intervention is shown in Table 2. The intervention spanned seven  
231 weeks in total. Week one and week seven were allocated to baseline and post-testing,  
232 respectively. Week two through to week five comprised the training period. Week six was  
233 allocated to a period of deload. During the main training period, progressive overload was  
234 achieved through a gradual increase in intensity (%1RM determined relative to either ECC<sub>1RM</sub>  
235 or CON<sub>1RM</sub>, as described below) each week, starting with a range between 82.5-87.5% 1RM  
236 in week one to 97.5-102.5% 1RM in week 4. To illustrate this progression, in week 1 for both  
237 leg press and back squat exercises, participants performed sets of 3 repetitions at 82.5%, 85%  
238 and 87.5% 1RM. In the final training week participants performed the same sets and exercises  
239 with loads of 97.5%, 100% and 102.5% of 1RM. Table 2 provides full details of the exercise  
240 intervention and programming variables.

241

242 Participants performed the same S&C programme, the only difference was in the load  
243 prescription for leg press exercise. The AEL and AEL-ATH groups performed coupled  
244 eccentric-concentric leg press exercise with load for the eccentric and concentric phase  
245 prescribed relative to  $ECC_{1RM}$  and  $CON_{1RM}$ , respectively, thereby offering a precise overload  
246 of the eccentric phase. The TRAD group performed coupled eccentric-concentric leg press  
247 exercise with the same load during both phases, which was prescribed relative to  $CON_{1RM}$ . The  
248 AEL-ATH group also continued their on-bike track sprint cycling training.

249 **Table 2. Overview of the training intervention. The AEL and AEL-ATH groups performed leg press exercise with an augmented eccentric**  
 250 **(ECC) phase (the ECC intensity was set relative to maximum ECC strength). The TRAD group performed leg press exercise in a**  
 251 **traditional manner where both concentric (CON) and ECC phases were prescribed to CON repetition maximum strength.**

		Training overview						
Week number		1	2	3	4	5	6	7
<b>Objectives</b>		Familiarisation Strength assessment	Training 1	Training 2	Training 3	Training 4	Deload	Strength assessment
<b>Intensity classification</b>		Very heavy	Moderate	Moderate-Heavy	Heavy	Very Heavy	Moderate	Very Heavy
<b>Sessions per week</b>		2	2	2	2	2	2	2
		<b>Exercise prescription (Sets × Reps %1RM)</b>						
		*Leg press load was set relative to ECC <sub>1RM</sub> for AEL and AEL-ATH, and relative to CON <sub>1RM</sub> for TRAD						
<b>1</b>	<b>Leg press*</b>	Max	4×3 82.5-87.5%	4×3 87.5-92.5%	4×3 92.5-97.5%	4×3 97.5-102.5%	3×3 82.5%	Max
<b>2</b>	<b>Back squat</b>	Max	3×3 82.5-87.5%	3×3 87.5-92.5%	3×3 92.5-97.5%	3×3 97.5-102.5%	3×3 82.5-87.5%	Max
<b>3</b>	<b>Pull from floor</b>	N/A	3×6 70-75%	3×6 70-75%	3×6 70-75%	3×6 70-75%	3×3 70%	N/A
	<b>Conditioning circuit:</b>	N/A	3 rounds:	3 rounds:	3 rounds:	3 rounds:	N/A	N/A
<b>4a</b>	SL goblet squat		×8 reps	×8 reps	×8 reps	×8 reps		
<b>4b</b>	Isometric trunk hold		×30 s	×30 s	×30 s	×30 s		
<b>4c</b>	Lying leg raise		×10 reps	×10 reps	×10 reps	×10 reps		

252

## 253 **Statistical analysis**

254 Values are reported as mean  $\pm$  SD. All data sets were checked for normality using Shapiro-  
255 Wilk's test ( $p \leq 0.05$ ). Programme characteristics were examined using a one-way ANOVA to  
256 determine the differences in training intensity between the TRAD, AEL and AEL-ATH groups.  
257 To assess the effect of training, mixed  $2 \times 3$  ANOVAs with a within-subject factor of time  
258 (Pre- vs. Post-training) and between-subjects factor of group (TRAD vs. AEL vs. AEL-ATH)  
259 were performed to assess changes in strength diagnostics. The main ANOVA models included  
260  $\eta_p^2$  effect sizes, and significant main effects were followed by Least Significant Difference  
261 *post-hoc* tests. Relative changes from pre- to post-training are presented using forest plots  
262 displayed as  $\bar{x} \pm 95\%$  CI, with an illustration of the measurement error of the test. Hedges  $g$   
263 was used to quantify effect sizes, interpreted as small ( $>0.2$ ), medium ( $>0.5$ ) and large ( $>0.8$ )  
264 [24]. Statistical significance was accepted at  $p < 0.05$ .

265

## 266 **Results**

267

268 **Programme characteristics.** Relative training intensity performed during the concentric  
269 phase was not different between the three groups ( $F_{(2, 21)} = 2.3, p = 0.12, \eta_p^2 = 0.18$ ). Relative  
270 training intensity performed during the eccentric phase was different between groups ( $F_{(2, 21)}$   
271  $= 24.5, p < 0.01, \eta_p^2 = 0.70$ ), whereby TRAD trained with lower relative intensity compared to  
272 both AEL ( $-8.42 \text{ N}\cdot\text{kg}^{-1}, -11.74$  to  $-5.09 \text{ N}\cdot\text{kg}^{-1}$ ) and AEL-ATH ( $-6.80 \text{ N}\cdot\text{kg}^{-1}, -10.12$  to  $-3.48$   
273  $\text{N}\cdot\text{kg}^{-1}$ ). The AEL-ATH and AEL groups performed the eccentric phase with  $26 \pm 4\%$  greater  
274 intensity across the training intervention compared to TRAD.

275

276 **Strength diagnostics.** All training groups experienced increases in strength post-training.  
277 Eccentric repetition maximum increased for all groups (Table 3, Fig 1), with no difference  
278 between groups in the magnitude of change (group  $\times$  time  $p = 0.25$ , Table 3), which equated to  
279 effect sizes of 0.7, 0.4, and 0.3 for AEL, TRAD, and AEL-ATH respectively. Both the TRAD  
280 and AEL groups improved ISO<sub>90</sub> (AEL,  $p < 0.01$ ,  $g = 0.7$ ; TRAD,  $p = 0.04$ ,  $g = 0.4$ ), and  
281 CON<sub>1RM</sub> (AEL,  $p < 0.01$ ,  $g = 0.5$ ; TRAD  $p = 0.02$ ,  $g = 0.3$ ) strength post-training. The change  
282 in ISO<sub>90</sub> (1.8 N·kg<sup>-1</sup>, -0.1 to 3.7 N·kg<sup>-1</sup>,  $p = 0.06$ ,  $g = 0.4$ ) and CON<sub>1RM</sub> (1.1 N·kg<sup>-1</sup>, -0.2 to 2.4  
283 N·kg<sup>-1</sup>,  $p = 0.10$ ,  $g = 0.2$ ) for the AEL-ATH group did not attain statistical significance.

284

285 **Fig 1.** Relative changes ( $\pm$  95% confidence intervals) in strength following training with (AEL,  
286 AEL-ATH) and without (TRAD) augmented eccentric loading. Shaded bars represent the  
287 measurement error for each outcome measure. *a*, different from TRAD, *b*, different from AEL  
288 ( $p < 0.05$ ).

289

290 **Table 3. ANOVA model statistics, and changes in strength diagnostics following training with (AEL, AEL-ATH) and without (TRAD)**  
 291 **augmented eccentric loading. Significant pre- to post-training changes within-group are denoted with \* ( $p < 0.05$ )**

Variable	Group	ANOVA																	
		PRE						POST			Group			Time			Group x Time		
		$\bar{x}$	$\pm$	SD	$\bar{x}$	$\pm$	SD	$F$	$p$	$\eta_p^2$	$F$	$p$	$\eta_p^2$	$F$	$p$	$\eta_p^2$			
CON <sub>1RM</sub> (N·kg <sup>-1</sup> )	TRAD	32.2	$\pm$	4.4	33.7	$\pm$	3.75*												
	AEL	34.1	$\pm$	4.5	36.3	$\pm$	3.57*	1.49	0.26	0.18	22.60	< 0.01	0.62	0.91	0.43	0.12			
	AEL-ATH	36.8	$\pm$	5.0	37.9	$\pm$	4.60*												
ISO <sub>90</sub> (N·kg <sup>-1</sup> )	TRAD	33.3	$\pm$	4.9	35.1	$\pm$	3.91*												
	AEL	34.5	$\pm$	4.6	37.6	$\pm$	3.37*	0.88	0.44	0.11	22.45	< 0.01	0.62	0.91	0.43	0.12			
	AEL-ATH	36.8	$\pm$	5.2	38.6	$\pm$	4.74												
ECC <sub>1RM</sub> (N·kg <sup>-1</sup> )	TRAD	35.7	$\pm$	5.5	38.0	$\pm$	5.13*												
	AEL	40.4	$\pm$	5.2	44.6	$\pm$	5.40*	2.15	0.15	0.24	38.93	< 0.01	0.74	1.56	0.25	0.18			
	AEL-ATH	42.2	$\pm$	7.1	44.8	$\pm$	7.36*												
TRAD <sub>1RM</sub> (N·kg <sup>-1</sup> )	TRAD	34.6	$\pm$	5.3	33.4	$\pm$	5.50												
	AEL	36.5	$\pm$	3.6	39.4	$\pm$	3.53*	2.42	0.15	0.20	1.05	0.33	0.10	7.36	0.02	0.42			
	AEL-ATH																		
SQ <sub>3RM</sub> (kg·BW <sup>-1</sup> )	TRAD	1.59	$\pm$	0.27	1.66	$\pm$	0.25*												
	AEL	1.70	$\pm$	0.19	1.78	$\pm$	0.14*	0.54	0.60	0.07	61.23	< 0.01	0.81	7.47	0.01	0.52			
	AEL-ATH	1.62	$\pm$	0.18	1.83	$\pm$	0.15*												

292 CON<sub>1RM</sub>, leg press concentric maximum force; ISO<sub>90</sub>, leg press isometric maximum force at 90° knee angle; ECC<sub>1RM</sub>, leg press eccentric maximum force; TRAD<sub>1RM</sub>, coupled eccentric-concentric  
 293 leg press maximum force; SQ<sub>3RM</sub>, three repetition maximum back squat relative to body mass  
 294

295 For SQ<sub>3RM</sub> and leg press TRAD<sub>1RM</sub> there were significant group × time interactions.  
296 Specifically the AEL-ATH group increased SQ<sub>3RM</sub> to a greater extent (g = 1.1) than both AEL  
297 (p < 0.01, g = 0.4) and TRAD (p = 0.01, g = 0.3) (Table 3, Fig 1). For leg press TRAD<sub>1RM</sub> there  
298 was no main effect for time (p = 0.33) however the increase in the AEL group (2.93 N·kg<sup>-1</sup>,  
299 0.46 to 5.40 N·kg<sup>-1</sup>, g = 0.8) was different to the slight decrease in the TRAD group (-1.32  
300 N·kg<sup>-1</sup>, -3.80 to 1.15 N·kg<sup>-1</sup>, g = -0.2, group × time p = 0.02). The AEL-ATH group did not  
301 perform leg press TRAD<sub>1RM</sub> post-testing due to the aforementioned, unexpected, residual  
302 fatigue.

303

304

## Discussion

305 The aim of this work was to ascertain the feasibility and efficacy of training with a novel leg  
306 press device, that affords an overload of muscle lengthening actions, in well-trained strength  
307 athletes and professional sprint track cyclists. Four weeks of eccentric strength training  
308 provoked improvements in a range of strength diagnostics, with some evidence of greater  
309 magnitudes of improvement in comparison to traditional strength training. In a group of  
310 professional cyclists, a four-week eccentric training stimulus was successfully implemented,  
311 and efficacious at improving measures of muscular strength, including a relatively greater  
312 increase in 1RM squat strength. Thus, a short-term (4 weeks, 8 sessions) eccentric strength  
313 training programme was efficacious, and well-tolerated by well-trained strength athletes and  
314 sprint track cyclists, and offers a novel training exercise to improve indices of muscle strength.

315

316 The four-week training programme employed was sufficient to provoke improvements in a  
317 range of strength characteristics, with some specific differences between groups in training-  
318 induced changes in strength. All groups improved concentric, eccentric and isometric leg press



319 strength, and the magnitudes of improvement were comparable to those previously reported  
320 for strength-trained individuals for short term (4 to 6 weeks) training [11, 17, 25], but less than  
321 that observed for longer-term (10-12 weeks) training incorporating augmented eccentric  
322 loading [16, 26]. The AEL group improved leg press 1 repetition maximum to a greater extent  
323 than the TRAD group, and the AEL-ATH group improved their squat 3 repetition maximum  
324 more than both TRAD and AEL. With respect to the AEL group, the greater increase in leg  
325 press 1RM compared to TRAD suggests a possible greater efficacy of training with augmented  
326 eccentric load. This is partially supported by a relatively greater change in concentric (7% vs.  
327 5%), eccentric (11% vs. 7%) and isometric (10% vs. 6%) strength in AEL compared to TRAD,  
328 however these interpretations should be treated with caution as none of these comparisons  
329 attained statistical significance. The training programme employed was relatively short (4  
330 weeks, 8 sessions), and it is plausible to speculate that a longer duration might have revealed  
331 further differences between groups. This notion is supported by the findings presented by  
332 Walker *et al.* [26] which highlight that the benefits of augmented eccentric loading for strength-  
333 trained individuals might take some time to manifest (more than five weeks). Thus, future  
334 research that builds on this preliminary data should consider implementing a longer training  
335 period.

336

337 The AEL-ATH group incorporated the eccentric overload stimulus alongside their usual S&C  
338 programme, and track cycling training. In this group there were large changes in squat  
339 repetition maximum strength that exceeded the magnitude of change observed in TRAD and  
340 AEL, and was greater than that previously reported in athletic cohorts [16, 17]. This was in  
341 contrast however to the relatively modest changes in concentric, eccentric and isometric  
342 strength. This can be explained in part by an unexpected interruption to the athletes training  
343 schedule during the post-testing period. Testing of squat repetition maximum was performed

344 on post-testing day 1 of 2, after a suitable deload period. However, on the second day of testing,  
345 which comprised leg press strength diagnostics, the AEL-ATH group were experiencing  
346 residual fatigue as a consequence of an unexpectedly high acute training load, and the  
347 preceding strength assessment. This also necessitated the termination of the testing procedures  
348 before the traditional leg press 1RM was assessed. The requirements for the organisation of  
349 post-testing and time allocated for recovery needed to be adapted for the AEL-ATH group to  
350 account for the logistical constraints surrounding full-time professional sport participation.  
351 These factors were beyond the experimenter's control, and as such the true impact of the  
352 training programme might not have been revealed as a consequence, though it is worth noting  
353 that both concentric and eccentric strength scores were higher, despite this residual fatigue  
354 compromising the testing schedule. This notwithstanding, the present study does demonstrate  
355 that strength training exercises overloading eccentric muscle actions can be feasibly  
356 incorporated into the training programme of full-time professional sprint track athletes, and  
357 could potentially provoke greater improvements in strength compared to traditional training.

358

359 A relatively novel feature of the study was the utilisation of a progressive loading approach  
360 based on muscle action specific 1RM for the eccentric and concentric phase across the training  
361 period. The training intensity experienced by the AEL and AEL-ATH groups was 23-30%  
362 higher during the leg press exercise, because of the progressive overload of the eccentric phase  
363 of the exercise. Previous work has typically programmed load for the eccentric phase relative  
364 to concentric strength [16, 17, 25, 26], whereas the approach adopted here allowed for the  
365 exploitation of the greater force producing capacity associated with eccentric muscle actions  
366 [5 {Hortobagyi, 1996 #1662, 6, 8}], whilst accounting for individual differences in eccentric  
367 strength. The optimal prescription of augmented eccentric load is unknown, but this range  
368 could provide a suitable guideline for those practitioners that do not have access to equipment

369 that facilitates the safe evaluation of eccentric-specific strength. A limitation of this approach  
370 is the inability to match volume between groups. Exercise volume is a key factor in resistance  
371 training prescription and, given the nature of the exercise prescription relative to their  
372 maximum eccentric force, the AEL group would have experienced a greater volume compared  
373 to TRAD. Coratella *et al.* [27] recently highlighted the importance of matching volume in  
374 resistance training studies. Though this wasn't achieved in the present study, the approach  
375 taken here is arguably more ecologically valid, as typically practitioners using AEL would aim  
376 to exploit the higher force-producing capacity of eccentric muscle actions. Further research to  
377 uncover the mechanisms underpinning adaptation to different forms of training would benefit  
378 from a more controlled approach [27].

379

380 The results of this study support the efficacy of training with augmented eccentric loading for  
381 improving leg strength qualities in well-trained athletes. A further important practical  
382 application is the palatability of the training stimulus in a full-time, professional athletic  
383 population. The AEL-ATH group successfully incorporated the eccentric training stimulus  
384 alongside their usual sport-specific training programme, with no adverse outcomes reported.  
385 Anecdotally, a number of riders also verbally reported increased feelings of stability when  
386 returning to their usual compound lifts, which was reflected in the large improvements  
387 demonstrated in squat strength. A limitation of the current work is the relatively small sample  
388 sizes and short duration of the study have hindered any conclusions on the relative superiority  
389 of augmented eccentric loading, and the logistical constraints imposed by testing a professional  
390 population rendered more sport-specific assessment unfeasible. Furthermore, the similarity of  
391 the testing modality (leg press strength in isometric, concentric, eccentric, and traditional  
392 modes) to the training stimulus, and the known specificity of adaptation to eccentric loading  
393 [28] also limits the generalisability of the results to other movements. Further work is

394 warranted to ascertain whether the improved strength offered by AEL using leg press exercise  
395 leads to improvements in other, sport-specific movements. Nonetheless, the results  
396 demonstrate that training with augmented eccentric loading is efficacious at improving leg  
397 strength in well-trained athletes, and can feasibly be incorporated into a professional, full-time  
398 athlete programme with no adverse consequences.

399

400 The approach to exercise prescription in this study was high in ecological validity; loads were  
401 prescribed in an attempt to optimise the stress of the AEL stimulus at the expense of matching  
402 for volume load, and the leg press exercise was incorporated into the wider resistance training  
403 program and was thus executed alongside other exercises. While this approach reflects what  
404 would occur in practice, it limits the ability to attribute causation given that the leg press  
405 stimulus was not the sole strength exercise the groups were performing. In an attempt to isolate  
406 the effect of the leg press stimulus, the additional training performed by all groups was matched  
407 for volume, intensity, and muscle action type. As a consequence, the only difference between  
408 groups was in the prescription of leg press exercise; this increases our confidence that the  
409 observed differences between groups could be due to the differing exercise prescription,  
410 however it does not allow us to isolate the effect of the leg press exercise *per se*.

411

412 A final potential limitation of the study is that the AEL-ATH group were younger than the AEL  
413 and TRAD groups. The AEL-ATH group were full-time, professional track cyclists who,  
414 though young in chronological age, were experienced with resistance training (>2 years), and  
415 were exhibiting levels of leg strength that were not different to the other groups. Anecdotally,  
416 the athletes in this group were reaching a plateau in their response to resistance training and  
417 the load required to achieve overload in traditional compound movements was becoming so  
418 high as to negatively impact their sport-specific training. However, given the younger age of

419 this group, it is not possible to discount the possibility that they had a relatively greater capacity  
420 for adaptation, and thus the greater increase in squat strength observed in the AEL-ATH group  
421 could be partly attributed to their younger training age.

422

423 In conclusion, four weeks of resistance training that incorporated augmented eccentric load,  
424 imposed via a novel leg press device, provoked marked adaptation in a range of muscle strength  
425 qualities, with some evidence of greater magnitude of improvements compared to traditional  
426 resistance training. The eccentric training stimulus imposed a greater demand compared to  
427 traditional resistance training, but this was well-tolerated by all participants, including a group  
428 of sprint track cyclists. This indicates that training with augmented eccentric load is both  
429 feasible, and efficacious for athletes aiming to improve muscle strength qualities. Future  
430 research studying training over longer time periods is warranted to fully understand the longer-  
431 term consequences and adaptations to this type of training.

432

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434

435

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## References

- 440 1. Stone MH, Moir G, Glaister M, Sanders R. How much strength is necessary? *Phys Ther*  
441 *Sport.* 2002;3(2):88-96. doi: 10.1054/ptsp.2001.0102. PubMed PMID:  
442 WOS:000177953800005.
- 443 2. Suchomel TJ, Nimphius S, Stone MH. The Importance of Muscular Strength in Athletic  
444 Performance. *Sports Medicine.* 2016;46(10):1419-49. Epub 2016/02/04. doi: 10.1007/s40279-  
445 016-0486-0. PubMed PMID: 26838985.
- 446 3. Lauersen JB, Bertelsen DM, Andersen LB. The effectiveness of exercise interventions  
447 to prevent sports injuries: a systematic review and meta-analysis of randomised controlled  
448 trials. *British Journal of Sports Medicine.* 2014;48(11):871-7. Epub 2013/10/09. doi:  
449 10.1136/bjsports-2013-092538. PubMed PMID: 24100287.
- 450 4. DeWeese BH, Hornsby G, Stone M, Stone MH. The training process: Planning for  
451 strength-power training in track and field. Part 1: Theoretical aspects. *J Sport Health Sci.*  
452 2015;4:308-17. PubMed PMID: WOS:000368609700003.
- 453 5. Franchi MV, Atherton PJ, Reeves ND, Fluck M, Williams J, Mitchell WK, et al.  
454 Architectural, functional and molecular responses to concentric and eccentric loading in human  
455 skeletal muscle. *Acta Physiol (Oxf).* 2014;210(3):642-54. Epub 2014/01/07. doi:  
456 10.1111/apha.12225. PubMed PMID: 24387247.
- 457 6. Hortobagyi T, Hill JP, Houmard JA, Fraser DD, Lambert NJ, Israel RG. Adaptive  
458 responses to muscle lengthening and shortening in humans. *J Appl Physiol (1985).*  
459 1996;80(3):765-72. Epub 1996/03/01. doi: 10.1152/jappl.1996.80.3.765. PubMed PMID:  
460 8964735.
- 461 7. Higbie EJ, Cureton KJ, Warren GL, 3rd, Prior BM. Effects of concentric and eccentric  
462 training on muscle strength, cross-sectional area, and neural activation. *J Appl Physiol (1985).*  
463 1996;81(5):2173-81. Epub 1996/11/01. doi: 10.1152/jappl.1996.81.5.2173. PubMed PMID:  
464 8941543.
- 465 8. Cadore EL, Gonzalez-Izal M, Pallares JG, Rodriguez-Falces J, Hakkinen K, Kraemer  
466 WJ, et al. Muscle conduction velocity, strength, neural activity, and morphological changes  
467 after eccentric and concentric training. *Scandinavian Journal of Medicine and Science in*  
468 *Sports.* 2014;24(5):e343-52. Epub 2014/05/17. doi: 10.1111/sms.12186. PubMed PMID:  
469 24833263.
- 470 9. Hakkinen K, Komi PV, Alen M, Kauhanen H. EMG, muscle fibre and force production  
471 characteristics during a 1 year training period in elite weight-lifters. *European Journal of*  
472 *Applied Physiology and Occupational Physiology.* 1987;56(4):419-27. Epub 1987/01/01. doi:  
473 10.1007/bf00417769. PubMed PMID: 3622485.
- 474 10. Baker DG. 10-year changes in upper body strength and power in elite professional  
475 rugby league players--the effect of training age, stage, and content. *Journal of Strength and*  
476 *Conditioning Research.* 2013;27(2):285-92. Epub 2013/01/30. doi:  
477 10.1519/JSC.0b013e318270fc6b. PubMed PMID: 23358318.
- 478 11. Coratella G, Schena F. Eccentric resistance training increases and retains maximal  
479 strength, muscle endurance, and hypertrophy in trained men. *Applied Physiology, Nutrition*  
480 *and Metabolism.* 2016;41(11):1184-9. Epub 2016/11/02. doi: 10.1139/apnm-2016-0321.  
481 PubMed PMID: 27801598.
- 482 12. Brandenburg JP, Docherty D. The effects of accentuated eccentric loading on strength,  
483 muscle hypertrophy, and neural adaptations in trained individuals. *Journal of Strength and*  
484 *Conditioning Research.* 2002;16(1):25-32. Epub 2002/02/09. PubMed PMID: 11834103.
- 485 13. Coratella G, Milanese C, Schena F. Unilateral eccentric resistance training: A direct  
486 comparison between isokinetic and dynamic constant external resistance modalities. *European*

487 Journal of Sport Science. 2015;15(8):720-6. Epub 2015/08/21. doi:  
488 10.1080/17461391.2015.1060264. PubMed PMID: 26289478.

489 14. Colliander EB, Tesch PA. Effects of eccentric and concentric muscle actions in  
490 resistance training. *Acta Physiologica Scandinavia*. 1990;140(1):31-9. Epub 1990/09/01. doi:  
491 10.1111/j.1748-1716.1990.tb08973.x. PubMed PMID: 2275403.

492 15. Vikne H, Refsnes PE, Ekmark M, Medbo JI, Gundersen V, Gundersen K. Muscular  
493 performance after concentric and eccentric exercise in trained men. *Medicine and Science in  
494 Sports and Exercise*. 2006;38(10):1770-81. Epub 2006/10/05. doi:  
495 10.1249/01.mss.0000229568.17284.ab. PubMed PMID: 17019299.

496 16. Cook CJ, Beaven CM, Kilduff LP. Three weeks of eccentric training combined with  
497 overspeed exercises enhances power and running speed performance gains in trained athletes.  
498 *Journal of Strength and Conditioning Research*. 2013;27(5):1280-6. Epub 2012/07/24. doi:  
499 10.1519/JSC.0b013e3182679278. PubMed PMID: 22820207.

500 17. Douglas J, Pearson S, Ross A, McGuigan M. Effects of Accentuated Eccentric Loading  
501 on Muscle Properties, Strength, Power, and Speed in Resistance-Trained Rugby Players.  
502 *Journal of Strength and Conditioning Research*. 2018;32(10):2750-61. Epub 2018/08/17. doi:  
503 10.1519/JSC.0000000000002772. PubMed PMID: 30113915.

504 18. Harden M, Wolf A, Haff GG, Hicks KM, Howatson G. Repeatability and Specificity  
505 of Eccentric Force Output and the Implications for Eccentric Training Load Prescription.  
506 *Journal of Strength and Conditioning Research*. 2019;33(3):676-83. Epub 2019/02/23. doi:  
507 10.1519/JSC.0000000000002965. PubMed PMID: 30789858.

508 19. Harden M, Wolf A, Russell M, Hicks KM, French D, Howatson G. An Evaluation of  
509 Supramaximally Loaded Eccentric Leg Press Exercise. *Journal of Strength and Conditioning  
510 Research*. 2018;32(10):2708-14. Epub 2018/02/23. doi: 10.1519/JSC.0000000000002497.  
511 PubMed PMID: 29470362.

512 20. Newton RU, Kraemer WJ, Hakkinen K. Effects of ballistic training on preseason  
513 preparation of elite volleyball players. *Medicine and Science in Sports and Exercise*.  
514 1999;31(2):323-30. Epub 1999/03/04. doi: 10.1097/00005768-199902000-00017. PubMed  
515 PMID: 10063823.

516 21. Marcora S, Miller MK. The effect of knee angle on the external validity of isometric  
517 measures of lower body neuromuscular function. *Journal of Sports Sciences*. 2000;18(5):313-  
518 9. Epub 2000/06/16. doi: 10.1080/026404100402377. PubMed PMID: 10855677.

519 22. Zaras ND, Stasinaki AN, Methenitis SK, Krase AA, Karampatsos GP, Georgiadis GV,  
520 et al. Rate of Force Development, Muscle Architecture, and Performance in Young  
521 Competitive Track and Field Throwers. *Journal of Strength and Conditioning Research*.  
522 2016;30(1):81-92. Epub 2015/06/08. doi: 10.1519/JSC.0000000000001048. PubMed PMID:  
523 26049793.

524 23. Banyard HG, Nosaka K, Haff GG. Reliability and Validity of the Load-Velocity  
525 Relationship to Predict the 1RM Back Squat. *Journal of Strength and Conditioning Research*.  
526 2017;31(7):1897-904. Epub 2016/09/27. doi: 10.1519/JSC.0000000000001657. PubMed  
527 PMID: 27669192.

528 24. Lakens D. Calculating and reporting effect sizes to facilitate cumulative science: a  
529 practical primer for t-tests and ANOVAs. *Front Psychol*. 2013;4:863. Epub 2013/12/11. doi:  
530 10.3389/fpsyg.2013.00863. PubMed PMID: 24324449; PubMed Central PMCID:  
531 PMC3840331.

532 25. Friedmann-Bette B, Bauer T, Kinscherf R, Vorwald S, Klute K, Bischoff D, et al.  
533 Effects of strength training with eccentric overload on muscle adaptation in male athletes.  
534 *European Journal of Applied Physiology*. 2010;108(4):821-36. Epub 2009/11/26. doi:  
535 10.1007/s00421-009-1292-2. PubMed PMID: 19937450.

536 26. Walker S, Blazevich AJ, Haff GG, Tufano JJ, Newton RU, Hakkinen K. Greater  
537 Strength Gains after Training with Accentuated Eccentric than Traditional Isoinertial Loads in  
538 Already Strength-Trained Men. *Frontiers in Physiology*. 2016;7:149. Epub 2016/05/21. doi:  
539 10.3389/fphys.2016.00149. PubMed PMID: 27199764; PubMed Central PMCID:  
540 PMC4847223.

541 27. Coratella G, Longo S, Ce E, Esposito F, de Almeida Costa Campos Y, Pereira  
542 Guimaraes M, et al. Commentaries on Viewpoint: Distinct modalities of eccentric exercise:  
543 different recipes, not the same dish. *J Appl Physiol (1985)*. 2019;127(3):884-91. Epub  
544 2019/09/17. doi: 10.1152/jappphysiol.00496.2019. PubMed PMID: 31525315.

545 28. Roig M, O'Brien K, Kirk G, Murray R, McKinnon P, Shadgan B, et al. The effects of  
546 eccentric versus concentric resistance training on muscle strength and mass in healthy adults:  
547 a systematic review with meta-analysis. *British Journal of Sports Medicine*. 2009;43(8):556-  
548 68. Epub 2008/11/05. doi: 10.1136/bjism.2008.051417. PubMed PMID: 18981046.

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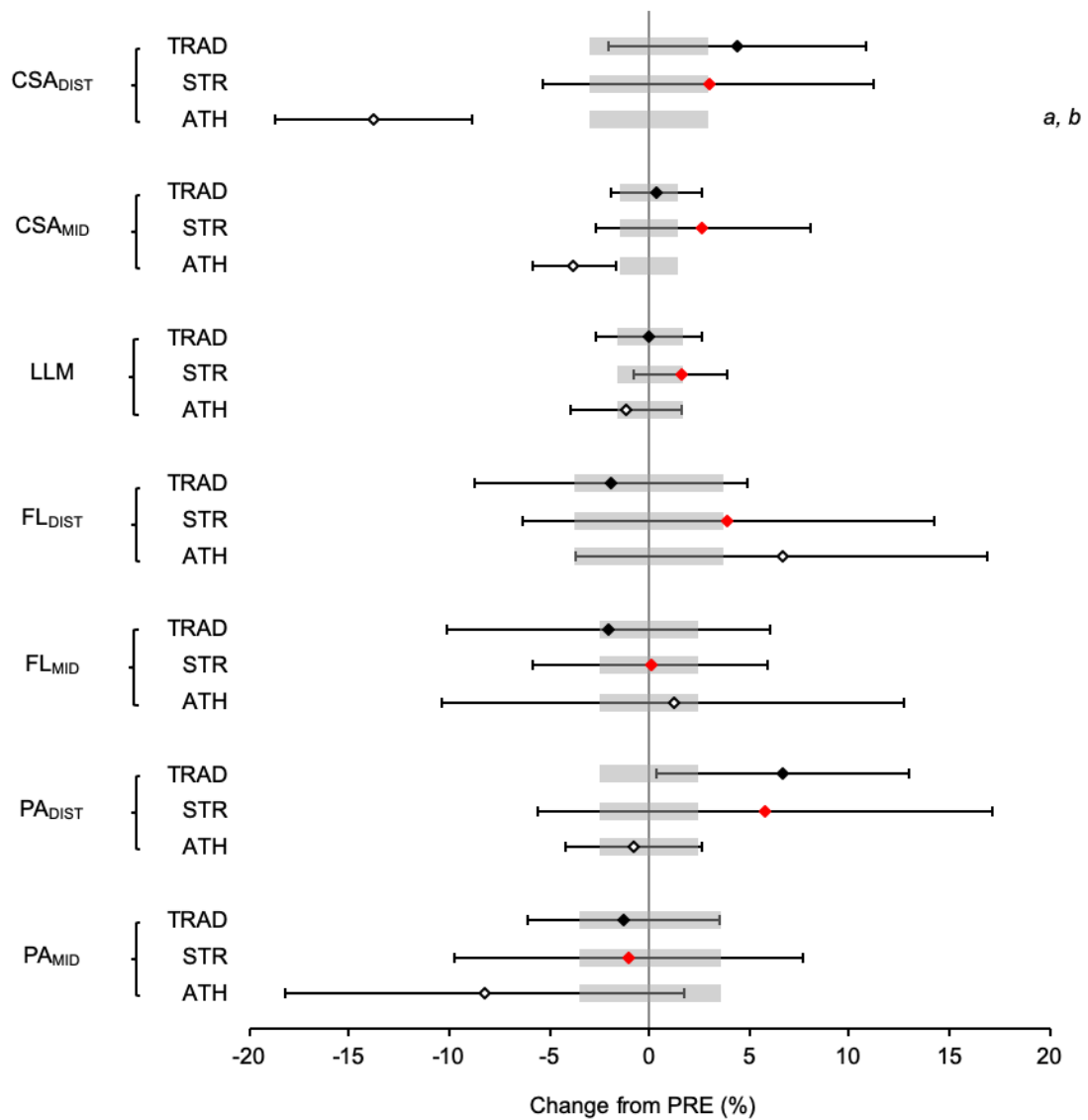
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555 **Figures**



556

557 Fig 1. Relative changes ( $\pm$  95% confidence intervals) in strength following training with (AEL,  
 558 AEL-ATH) and without (TRAD) augmented eccentric loading. Shaded bars represent the  
 559 measurement error for each outcome measure. *a*, different from TRAD, *b*, different from AEL  
 560 ( $p < 0.05$ ).

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