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1 ***Title: Effects of a lighter discus on shoulder muscle activity in elite throwers,***
2 ***implications for injury prevention***

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4 ***Running title: Using a lighter discus in elite discus throw***

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26 **ABSTRACT**

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28 **Background:** Performance in discus throw requires high forces and torques generated from
29 the shoulder of the throwing arm, making shoulder muscles at risk of overuse injury. Little is
30 known on muscle activation patterns in elite discus throw.

31 **Hypothesis/Purpose:** The purpose of this study was to examine the kinetics and shoulder
32 muscle activation during discus throws by using two discs of different mass. It was
33 hypothesized that the use of a lighter discus would modify the activation of the shoulder
34 musculature compared to a standard discus.

35 **Study design:** Case-control laboratory study

36 **Methods:** Seven male elite discus throwers performed five throws using a standard discus
37 (STD, 2.0 kg) and five throws using a lighter weight discus (LGT, 1.7 kg). Surface EMG was
38 recorded for the biceps brachii (BB), deltoideus anterior (DA), deltoideus medialis (DM),
39 clavicular head of the pectoralis major (PM), latissimus dorsi (LD), and trapezius medialis
40 (TM). Three-dimensional high-speed video analysis was utilised to record discus speed and
41 identify the different temporal phases of each throw from the preparation phase (P1) to the
42 delivery phase (P5).

43 **Results:** The EMG activation of LD lasted longer ($p < 0.01$) in P1 and was initiated later in
44 P5 with the LGT discus compared to STD. In P5, the EMG intensity of BB decreased ($p =$
45 0.02) with LGT (%EMGmax = $50.4 \pm 49.6\%$) compared to STD ($64.8 \pm 77.9\%$) and the
46 activation of PM increased ($p < 0.01$) with LGT ($86.2 \pm 40.3\%$) compared to STD ($66.2 \pm$
47 26.9%). The discus speed at release was increased ($p = 0.04$) by using the LGT discus (20.62
48 $\pm 0.75\text{m}\cdot\text{s}^{-1}$) compared to STD ($19.61 \pm 0.57\text{m}\cdot\text{s}^{-1}$). The throwing distance was also increased
49 ($P < 0.01$) with the LGT ($43.1 \pm 4.3\text{m}$) discus compared to STD ($39.4 \pm 3.4\text{m}$).

50 **Conclusion:** A lighter discus could be used by elite athletes in training to add variability in
51 muscle solicitation and thus limit the overload on certain muscles of the shoulder region.
52 These results may have implications to lower the risk of injury in discus throw.

53 **Clinical relevance:** The increase in shoulder muscle activity combined with the accelerated
54 forward swing of the throwing arm in P5 may help explain the incidence of muscle and
55 tendon injuries clinically observed in discus throw. Using a lighter discus in training may add
56 variability in muscle activity and motion kinetics to lower the mechanical load on the
57 shoulder and tendons.

58 **Levels of Evidence:** Level 3

59 **Keywords:** electromyography; discus throwing; performance; biceps brachii; upper limb;
60 training

61

62 **What is known about the subject:** Past studies have mainly focused on the body kinematics
63 required to perform in discus throw. The forces and torques required in discus throw are
64 generated through the lower body and are progressively transferred to the upper body and
65 more specifically to the shoulder joint of the throwing arm, which can suffer from overuse
66 injuries. [It has been reported that 70% of injuries in discus throw concern the ligaments,](#)
67 [tendons and muscles surrounding the shoulder area as well as the pectoralis major.](#) To date,
68 very little is known on the muscle activation pattern required to perform in discus throw and
69 whether it could be lowered by using a lighter discus in training. A better knowledge of
70 muscle activation in discus throw may have implication for training, injury prevention and
71 rehabilitation programs.

72

73 **What the study adds to existing knowledge:** Discus throwing requires a specific muscle
74 activation sequencing throughout the different phases of the throw. Muscle activation is the

75 highest during the last part of the throw, namely the delivery phase, which involves an
76 acceleration of the throwing arm to increase the release speed of the discus. Stabiliser muscles
77 are also almost constantly active during the throw to maintain the discus height and allow a
78 better transfer of the forces and torques from the lower to upper limbs. Using a lighter discus
79 during certain training sessions may help lower the mechanical load on muscles and tendons
80 of the shoulder region by adding some variability in the pattern of muscle activation. Based
81 on these new data, injury prevention and rehabilitation processes should also focus on the
82 phases with the highest muscle activity.

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100 **INTRODUCTION**

101

102 Discus throw requires technical and physical skills to perform complex movements at high
103 speed in a restricted area.¹⁻³ Performance in discus throw is measured by official distance and
104 mainly depends on the maximum speed, optimum height and specific angle of the discus at
105 release.^{1,4,5} Detailed analysis of the discus throw is generally carried out by subdividing the
106 motion into five consecutive phases (figure 1): i) preparation, a double support phase starting
107 from the change in discus direction at the end of its backward swing and ending when the
108 right foot breaks contact; ii) entry, a single support phase which ends with the left foot
109 breaking contact; iii) airborne, which ends with the right foot re-contacting; iv) transition, a
110 single support phase which ends as the left foot lands; v) delivery, which starts as a double
111 support phase and ends at release of the discus.¹⁻³ Each phase has a different influence on the
112 final throwing performance.^{2,5} Angular momentum of the discus in horizontal and vertical
113 components increases during the preparation and entry phases. The ground reaction forces
114 applied on the subject's feet during the entry phase increase the forward speed of the thrower-
115 discus system.² The loss of discus speed needs to be reduced using an optimal duration of
116 airborne phase.⁴ The ground reaction forces applied to the subject's feet during the last two
117 phases (transition and delivery) are also significantly correlated with the final performance.²
118 Finally, the majority of horizontal and vertical velocities are increased by the thrower during
119 the delivery phase.^{4,6} According to Yu et al.², lower limbs support important loads during the
120 different phases of entry, transition and delivery. Indeed, a positive correlation was found
121 between the increase in vertical speed from the foot opposite to the throwing arm and the
122 official distance. As such it is well known that performance in discus throwing is strongly
123 influenced by the activity of lower limbs. On the contrary little information is known on the

124 physical load applied to upper limbs which yet drive the discus during the entire duration of
125 the throw.^{3,5}

126 The influence of upper limbs on the discus thrower's performance has only been
127 observed through the study of body coordination (i.e. temporal activation of body segments
128 and joints) during the throw, showing that the lowest variability in the arm-shoulder kinematic
129 pattern generally leads to the best performance.^{3,5} However, it is reported that the shoulder
130 region accounts for 70 % of upper limb injuries in elite throwers.⁷ Although a robust
131 kinematic pattern would be required to perform at high level, repeating the exact same
132 movement and mobilising the same level of muscle activation over a long period of time
133 could accentuate the physical load on muscles and joints involved in discus throw. Indeed, a
134 low motor variability is commonly associated with a higher occurrence of physiological and
135 musculoskeletal disorders, potentially increasing the risk of injury.⁸ Edouard et al.⁷ reported
136 that 75% of national level throwers (including shot put, discus throw, hammer throw, javelin
137 throw) had presented one or more injuries of the throwing arm during their career. In the same
138 study, 40% of the injuries required an average 28 day break in training. The forces and
139 torques required in discus throw are generated through the lower body and are progressively
140 transferred to the arm throughout the whole movement, from the entry to delivery phase. As
141 such, throwers place axial, translational and distraction forces across the glenohumeral,
142 acromioclavicular and sternoclavicular joints which can suffer from overuse injuries over
143 time.⁹ In addition, carrying and stabilizing the discus throughout the throw would involve a
144 high muscle activation of certain muscles of the shoulder-arm region.^{4,10} A sustained training
145 load before competition is also reported as one of the main factors of injury.¹¹ To date, little
146 information is available on the activation of upper limb muscles in discus throw and
147 additional research is warranted to determine ways of modifying the load applied to the
148 throwing arm.

149 As reported in other throwing sports such as handball¹² and shot put¹³, training with a
150 lighter ball or weight could improve the athlete's ability to throw at a faster arm speed.
151 Similarly, it can be hypothesized that training with a lighter discus could be used as a training
152 strategy to diminish the physical load during key periods of training, whilst acquiring new
153 abilities. Training with a lower discus mass of 1.7 kg is often used by lower level and young
154 athletes in order to improve their throwing motion abilities. To the best of our knowledge,
155 only one preliminary study focused on the utilisation of different discus masses on the body
156 kinematics of three male and two female elite discus throwers.¹⁴ Results suggested that only
157 the discus speed at release time was influenced by the discus mass, with no alteration of body
158 kinematics during the throw.¹⁴ However, potential changes in muscular patterns and
159 coordination during each phase of the throw were not investigated. Improving the knowledge
160 of muscle activation patterns during the specific phases of discus throw would allow a more
161 specific strength and conditioning preparation to help improve performance, reduce the risk of
162 injury and optimise rehabilitation processes.

163 Within this framework, the purpose of the present study was to compare the body
164 kinematics and muscle activation patterns of arm and shoulder muscles involved in discus
165 throwing when using discs of different mass (1.7 kg vs 2.0 kg). It was hypothesized that when
166 performing discus throws with a lighter discus, the activity of arm and shoulder muscles
167 would be lower [compared to throws with a standard discus](#).

168

169 **METHODS**

170

171 **Study design**

172 The objective of the study was to examine the body kinetics and activation of selected
173 shoulder muscles during a series of discus throws using discs of different mass (1.7 kg vs. 2.0

174 kg). During the throws, muscle activity was recorded by using surface electromyography
175 (sEMG) on the following muscles: BB, the long head of the biceps brachii; DA, the deltoideus
176 anterior; DM, the deltoideus medialis; PM, the clavicular head of the pectoralis major; LD,
177 the latissimus dorsi; and TM, the trapezius medialis. Descriptive statistics (mean \pm standard
178 deviation) were used to determine muscle activations by calculating normalized sEMG data as
179 a percent of the participant's maximum voluntary isometric contraction (%MVIC). In addition
180 to shoulder muscle activation, body kinetics and throwing performances were recorded for
181 each throw to examine the influence of the discus mass.

182

183 **Participants**

184 Seven volunteer right-handed discus throwers (mean \pm standard deviation: age = 23.0 \pm
185 3years; height = 1.90 \pm 0.06m; body mass = 108.0 \pm 19kg; personal best performance = 57.0
186 \pm 3.0m) participated in this study. The participants were the seven top discus throwers of the
187 National team. This study was approved by the National athletics association and the local
188 ethics committee and carried out in accordance with the Declaration of Helsinki. All the
189 athletes were informed of the objectives of the study and signed a consent form before
190 participating.

191

192 **Surface electromyography procedure**

193 All testing was carried out in the outside throwing area where the athletes [use to train on a](#)
194 [daily basis](#). The surface EMG (sEMG) activity was recorded using bipolar self-adhesive
195 surface electrodes (Blue Sensor M-OO-S Medicotest, France). These pairs of 1g-AgCl pre-
196 gelled electrodes (centre-to-centre inter-electrode distance of 2 cm) were applied on the
197 palpated belly of the 6 muscles in parallel with the muscle fibres at the midportion of each
198 muscle according to Seniam recommendations.¹⁵ In order to reduce impedance (<5k Ω) at the

199 interface between the skin and the surface electrodes, the participant's skin was prepared by
200 removing hair from the tested area, followed by light skin abrasion and alcohol cleaning. The
201 electrodes were secured with surgical tape and cloth wrap to minimize disruption during
202 movement.

203

204 **Surface electromyography normalizing procedure**

205 Prior to sEMG recordings, participants performed a 15min discus throwing specific warm-up
206 under supervision of the national coach. sEMG signals during maximal voluntary isometric
207 contractions (MVIC) were then collected as reference for normalization procedure.^{16,17} To
208 determine the maximum sEMG signal for the 6 muscles of the shoulder and arm regions,
209 three isometric contractions were performed and maintained for 3 to 5s.¹⁸ Prior to the three
210 maximal attempts, the athletes were familiarized with the procedure and asked to produce a
211 series of submaximal and gradually increasing contractions. The MVIC were then performed
212 according to the procedure described by Knudson and Blackwell¹⁹ and recently used by
213 Henning et al.²⁰ in softball players. Two sport physiologists administered the resistance by
214 manual exertion while a third assistant helped them by fixing the proximal body segment.
215 Participants were then instructed to produce a maximal effort in opposition to the external
216 resistance. Manual muscle testing was performed as follows: for DA and PM, participant
217 stood, arm extended and in 90° abduction in the frontal plane and 30° anterior flexion in the
218 sagittal plane, thumb oriented upward. The investigators applied a backward force onto the
219 wrist in the antero-posterior axis. For BB, participant stood, arm along the body with a 60°
220 elbow flexion in the sagittal plane with the forearm in supination. The investigators applied a
221 downward resistance onto the wrist in the vertical axis. For DM, participant stood, arm
222 extended and in 90° abduction in the frontal plane and with a 30° anterior flexion in the
223 sagittal plane. The thumb was oriented upward. The investigators applied a backward

224 resistance onto the wrist in the vertical axis. For TM, participant sat upright on a bench with a
225 90° knee flexion, arm extended along the body. The investigators applied a downward
226 resistance onto the wrist, in the vertical axis. For LD, the participant was lying prone with the
227 arms resting at the sides. The participant was asked to internally rotate the arm so that the
228 thumb faced towards the ground and raise it up away from the table into extension. The
229 investigators applied a force on the forearm in the direction of abduction and flexion.
230 Participants rested for 1 min between each contraction.^{19,21,22} The best performance
231 consecutive to the three trials determined the MVIC and was kept for the analysis.

232

233 **General procedures**

234 After completing the discus throwing specific warm-up and MVIC procedures, athletes went
235 to the throwing area and were instructed to perform twelve maximal discus throws according
236 to the criteria of realisation of the International Association of Athletics Federation (IAAF).

237 Six throws were performed using a standard 2.0kg competition discus (STD discus). The six
238 other throws were performed using a lighter 1.7kg discus (LGT discus). A passive 3min
239 recovery period was set between each throw to avoid cumulative muscular fatigue. The order
240 in which the discs were tested was randomized. The five best throws performed with the STD
241 and LGT discus were retained for analysis, allowing one bad/adjustment throw per condition.

242 These throws were higher than 80% of the athletes' personal best performance distance. The
243 measured distance of the discus throw was calculated by using the release speed, height and
244 angle of the discus according to the method described by Chow and Mondock.²³

245

246 **Video recording and motion analysis**

247 Each throw was recorded using three digital camcorders (Panasonic AG-455, 50 Hz). These
248 camcorders were located behind the throwing area and on both sides of the discus release area

249 with a 120° angle between each camcorder. The camcorders were placed 3m from the centre
250 of the discus release area. A calibration frame (2m x 2.5m x 2m) with 12 calibration points
251 was set out on the throwing area and used for spatial reference.²⁴ Each throw was recorded
252 from the instant the athlete began his double support phase starting from the change in discus
253 direction at the end of its backward swing until the end of the delivery phase. Additionally, as
254 described and depicted in figure 1, each throw was divided into 5 phases for a precise sEMG
255 and motion analysis during the entire throw: P1: preparation phase, P2: entry phase, P3:
256 airborne phase, P4: transition phase, P5: delivery phase.² Seventeen reflective markers were
257 identified on the thrower's right and left sides: the toes, the lateral malleolus, the lateral
258 epicondyle, the iliac spine, the acromion, the radial epicondyle, the stylium, the 3rd metacarpal,
259 the vertex of the head. One specific marker was placed on the discus geometrical centre. All
260 markers were manually digitized using a video data acquisition system (3D Vision,
261 Biometrics SA, France[®]). Direct linear transformation method was used to calculate the
262 markers' position in space.²⁵ Maximal error of the markers' position²⁶, based on the length of
263 the right forearm was 0.35cm. Data was filtered with a zero phase four-order Butterworth
264 filter. Cut-off frequencies were 12Hz.⁵ The marker's positions associated with anthropometric
265 data were used to determine the trajectory of the centre of mass (CoM) of the subject-discus
266 system. Each component of speed (VCoM) of the subject-discus system was computed. The
267 discus absolute speed was computed during each phase and at release time according to Chow
268 and Mondock.²³ The video data was synchronized with sEMG recordings during the entire
269 protocol using the same A/D converter so that motion analysis, sEMG activity, discus speed
270 and distance data were collected simultaneously during the entire protocol.

271

272 **Surface electromyography data processing**

273 sEMG data was sampled at 1000Hz and stored on a wireless ME3000P8 muscle tester
274 (Mega88 Electronics Ltd, Kuopio, Finland). The data was band pass filtered (10-500Hz)
275 before further analysis. The average envelope of rectified sEMG signal was computed with a
276 500ms moving windows for each phase of the entire throw. The onset and offset of muscle
277 activation were detected by using a three standard deviation (SD) threshold procedure.²⁷ The
278 mean sEMG value obtained from the moving averaged envelopes were then normalized by
279 the duration (%EMGt) of each phase to analyse the temporal activation level between the
280 different phases of the throw. Finally, the mean of the moving averaged envelope was
281 normalized by the sEMG value recorded during MVIC (%sEMGmax) in order to compare the
282 activation level of the different muscles.¹⁹

283

284 **Statistical analysis**

285 For each phase of the discus throw, the distribution of each variable was tested using
286 asymmetry and kurtosis coefficients. A two-way (discus mass x time) ANOVA test for
287 repeated measurements was used to analyse the impact of the discus mass on EMG (%EMGt
288 and %EMGmax), kinematic values (VCoM) and discus speed during the five phases of the
289 discus throw. When a significant difference was observed, a Newman-Keuls post-hoc test was
290 applied. The level of significance was set at $P < 0.05$.

291

292 **RESULTS**

293

294 **Comparison of the temporal muscle activation between discs**

295 The muscle activation patterns (EMGt) of the shoulder-arm region of the throwing arm are
296 displayed in figure 2. Overall, the temporal analysis of sEMG signals revealed a similar
297 activation pattern with the STD and LGT discs during the discus throw. Three muscle

298 activation periods were detected; the first at the initiation of the movement (phases P1-P2)
299 during which the trapezius medialis, deltoideus medialis and latissimus dorsi were activated;
300 the second situated in the middle of the throw (P2-P3) with the activation of the latissimus
301 dorsi; the third at the end of the throw (P4-P5) with the activation of the biceps brachii,
302 deltoideus anterior, pectoralis major, trapezius medialis and latissimus dorsi.

303 Only the latissimus dorsi presented a different ($P < .01$) temporal activation pattern
304 between STD and LGT discs. The end of the first sEMG activation period during the first
305 phases of the throw (P1-P2) occurred later with the LGT discus ($36.5 \pm 12.0\%$ of the total
306 duration of the entire throw) compared to STD ($30.9 \pm 6.6\%$). The initiation of the last sEMG
307 activation period (in P4) occurred later with the LGT discus ($80.0 \pm 8.1\%$) compared to STD
308 ($72.3 \pm 6.1\%$). No difference was observed for the temporal activation of the trapezius
309 medialis, deltoideus medialis, latissimus dorsi, biceps brachii, pectoralis major and deltoideus
310 anterior between both throwing conditions (Figure 2).

311

312 **Comparison of the intensity of muscle activation between discs**

313 Whatever the throwing condition (STD or LGT), the highest muscle activation (expressed as
314 %EMGmax) was recorded for muscles mainly active at the end of the transition phase (P4)
315 and during the delivery phase (P5). The biceps brachii displayed $92.9 \pm 27.1\%$ of muscle
316 activation in P4 and $64.8 \pm 77.9\%$ in P5, $84.6 \pm 17.3\%$ for the deltoideus anterior in P5 and
317 $66.2 \pm 26.9\%$ and $86.2 \pm 40.3\%$ for the pectoralis major in P4 and P5 respectively (figure 3).
318 The trapezius medialis, latissimus dorsi and deltoideus medialis were the most active muscles
319 during the first phases (P1 to P3) of the throw. Maximal sEMG activation values were $53.8 \pm$
320 10.7% for the trapezius medialis, $42.0 \pm 18.6\%$ for the latissimus dorsi and $35.8 \pm 8.2\%$ for
321 the deltoideus medialis (figure 3).

322 The intensity of muscle activation was different between STD and LGT discs only
323 during the delivery phase of throwing (Figure 3). The intensity of muscle activation was
324 increased ($P < .01$) for the pectoralis major with the LGT discus ($86.2 \pm 40.3\%$) compared to
325 STD ($66.2 \pm 26.9\%$). The intensity of muscle activation was reduced ($P = .02$) in P5 for the
326 biceps brachii with LGT ($50.4 \pm 49.6\%$) compared to STD ($64.8 \pm 77.9\%$). The intensity of
327 activation of the deltoideus anterior, trapezius medialis, deltoideus medialis and latissimus
328 dorsi was not significantly altered between throwing conditions ($P > .05$).

329

330 **Kinetic and performance variables**

331 Mean discus speed (figure 4) significantly increased ($P = .04$) only during the delivery phase
332 (P5) and in greater proportion by using the LGT discus ($20.62 \pm 0.75 \text{ m}\cdot\text{s}^{-1}$) compared to STD
333 ($19.61 \pm 0.57 \text{ m}\cdot\text{s}^{-1}$). The angle (36.4 ± 3.9 vs $36.0 \pm 3.2^\circ$ with STD and LGT respectively)
334 and height (1.65 ± 1.2 vs 1.69 ± 6.5 m with STD and LGT respectively) of the discus at
335 release time were not impacted by the different discus masses ($P > .05$, table 1).

336 The mean distance covered by the discus after release (table 1) was greater ($P < .01$)
337 by using the LGT discus (43.1 ± 4.3 m) compared to STD (39.4 ± 3.4 m).

338 The speed of the centre of mass of the thrower-discus system was not significantly
339 altered by the discus mass in all phases of the throw (table 1).

340

341 **DISCUSSION**

342

343 The aim of the present study was to compare the EMG activation patterns of muscles from the
344 arm-shoulder region at different phases of the discus throw when using a STD and LGT
345 discus. It was hypothesized that when performing throws with the LGT discus, the muscles of
346 the throwing arm-shoulder region would display a lower EMG activation compared to throws

347 performed with a STD discus. The study also aimed to investigate the potential alteration in
348 motion kinetics of the discus-thrower system and performance variables.

349

350 **Differences in muscle temporal activation between discs**

351 The results from the current study show that the temporal activation pattern of muscles
352 from the arm-shoulder region were almost identical when using the STD and LGT discus.
353 Only the temporal activation of LD was significantly altered during the first (in P1-P2) and
354 last activation periods (in P4-P5) with the LGT discus. This result suggests that the
355 distribution of muscle activation through the different phases of discus throwing was robust
356 enough to resist to changes in discus mass in elite throwers, thus partly rejecting the initial
357 hypothesis. Limiting the variability of the kinematics and muscular pattern has been
358 associated with a better efficiency in discus throw.⁵ The thrower may try to coordinate their
359 own muscular contractions in order to use a motor program adapted to their skills.^{5,28} Besides,
360 an understanding of muscles at work during the different phases throughout the throwing
361 cycle allows for a better assessment of the mechanical load imposed by the sport. As
362 displayed in figure 2, discus throwing requires an almost constant muscle activation of
363 stabiliser muscles (LD, DM, TM) during the whole movement. This specific muscle
364 activation sequencing is suggested to be a prerequisite to stabilise and accompany the
365 throwing arm towards the greatest release speed with the optimal discus angle at release. It is
366 also suggested that maintaining the discus height constant during the whole movement until
367 the delivery phase reflects the ability of the best athletes to reproduce the same motor
368 performance to provide optimum conditions for delivery.⁴ Even though the current study is
369 the first to report temporal muscle activation in discus throwing making comparisons with
370 other studies difficult, it is well known that the duration of the different throwing phases is
371 very consistent at elite level.^{4,29} The longest parts of the throw are reported to be the

372 preparation phase (P1) and entry (P2) during which stabiliser muscles are the most activated.
373 The entry phase is then followed by the airborne phase (P3) of very short duration in order to
374 minimise the loss of discus speed (figure 2). The goal of the thrower during this phase is to
375 initiate the separation of the hip axis over the shoulder axis and of the latter over the discus.
376 As such, P3 marks the transition between the activation of stabiliser and effector muscles.
377 This hip-shoulder separation required to increase the discus speed is then mainly obtained
378 during the transition phase (P4) during which the BB and PM muscles are activated. BB and
379 PM muscles allow the horizontal adduction/forward swing of the throwing arm till the
380 delivery phase (P5), while the DA and TM facilitate the opening of the release angle for
381 delivery.

382

383 **Differences in intensity of muscle activation between discs**

384 The analysis of the intensity of muscle activation (expressed as percent of maximal
385 activity during **MVIC**) provides more details on the understanding of the muscular solicitation
386 required to perform in discus throw. The first finding is that using a lighter discus slightly
387 modified the activity of PM and BB only during the delivery phase when they are the most
388 activated to place the throwing arm in the best condition for discus release. The activity of PM
389 was increased by 20% by using the LGT discus compared to STD, while the activity of BB
390 was lowered by 15% with the LGT discus. Even though these results were significant it seems
391 important to consider the large inter individual variability of EMG data (figure 3). As such it
392 can be hypothesised that the differences in EMG activity recorded between LGT and STD
393 conditions might reflect normal muscular and biomechanical adjustments of the athletes. This
394 result is in agreement with Peng and Huang¹⁰ and the data from Finanger's doctoral thesis³⁰
395 presented by Bartlett⁴ where the variability of EMG activity was the greatest for the BB.

396 Not surprisingly the highest muscle activity during the throw was recorded during the
397 delivery phase which requires high forces and torques of muscles from the trunk and
398 shoulder-arm region to propel and slightly open the arm forward. The PM, BB and DA all
399 reached more than 80% of maximal EMG activity during the delivery phase with slight
400 differences between LGT and STD discs as discussed earlier. An increasing muscle activity
401 during the delivery phase is paramount to accelerate the arm-discus speed till delivery. As
402 such, this phase could be described as an “acceleration phase” in reference to other throwing
403 activities such as Javelin throw, volleyball serve, tennis serve, baseball batting and softball
404 pitching.^{17,31} In discus throwing, the PM, BB and DA can be considered as the most important
405 “effector” muscles to help accelerate the arm and discus speed during this acceleration phase.
406 Consequently, even though these muscles are intermittently active, their ballistic (forward
407 swing) and high level of activation expose the throwing arm to a risk of overuse and injury.
408 Muscle, tendon and ligamentous injuries are the most common injuries with the shoulder
409 being the most injured body part (70%) in athletic throwing activities including the discus
410 throw, shot put, hammer throw and javelin throw.⁷ In discus throw, high torques and axial
411 loads placed across the glenohumeral joint can predispose to injury within the shoulder as
412 well as further distal in the kinetic chain.⁹ The shoulder is also particularly placed in an “at
413 risk” position during the delivery phase, that is, extreme horizontal abduction which may
414 cause rupture or tears of tendons, ligaments and muscles of the rotator cuff.³² The pectoralis
415 major can also be at risk of tears due to its hyperextension during the delivery phase.³³

416 The LD, TM and DM presented a constant medium to high EMG intensity during the
417 entire throw confirming their role of stabiliser muscles. More specifically, the LD presented
418 the highest activity with EMG values ranging from 35 to 60% of EMGmax during the entire
419 throw. These data show the great stress placed on the active stabilisation and control of body
420 kinematics during the entire throw. As such, stabiliser muscles could also be exposed to

421 excessive fatigue and even overuse in discus throwing. In addition, weaker stabiliser muscles
422 may fail to contain the shoulder joint and position of the throwing arm, thus exposing the
423 rotator cuff to excessive mechanical load to compensate for this. Consequently, overuse,
424 fatigue tendinitis, rotator cuff tear or impingement may occur.³²

425

426 **Differences in motion kinetics and performance between discs**

427 In addition to muscle activation levels, this study also investigated the motion kinetics
428 and performance variables between the discs tested. The results of the study confirm that the
429 discus speed significantly increases during the delivery phase (P5) and in greater proportion
430 when using the LGT discus. As demonstrated in previous publications, the majority of the
431 horizontal and vertical speeds are obtained during the delivery phase.^{1,4} Between 62% and
432 73% of the release speed of the discus could be generated during the delivery phase.⁴ Higher
433 performances are also commonly associated with higher release speeds. As such release speed
434 is reported to be the most influential determinant of the distance of the throw and the
435 emphasis in training should be brought on the attainment of a high discus speed at release. As
436 suggested by our results, using a lighter discus during training could serve this purpose by
437 allowing for a greater acceleration of the throwing arm from the second double support phase
438 initiated at the beginning of P5 (figure 4). While non-significant, the speed of the centre of
439 mass in P5 was reduced by using the LGT discus which could contribute to the attainment of
440 a greater acceleration of the throwing arm. Indeed, according to Susanka et al.²⁹, a rapid
441 achievement of the double support position with a stable and open delivery stance would
442 represent optimal conditions to reach maximal acceleration. On contrary to discus speed, the
443 angle and height of the discus at release were not modified by the discus mass between
444 throws. The majority of the studies have reported large variations in discus height between
445 throwers which is largely dependent on the thrower's height. With regards to the angle of the

446 discus at release, optimal angles range from 35 to 44° which is in agreement with our results.⁴
447 However the release angle may be influenced by the physical and technical characteristics of
448 the thrower and the wind conditions, head winds forcing the athletes to reduce the release
449 angle whereas tails winds could increase the angle.^{4,6} In the end, discus speed, height and
450 angle at release, should be optimised to maximise the discus spin and provide sufficient
451 gyroscopic stability for a long trajectory. In our study, the mean distance covered by the
452 discus after release was greater by using the LGT discus (43.1 ± 4.3 m) compared to STD
453 (39.4 ± 3.4 m) confirming that increasing the release speed is likely the most important
454 parameter for high performance in discus throw.

455

456 **Practical applications and limitations**

457 These data provide new evidence of the sustained **mechanical load** applied on both
458 stabiliser and effector muscles of the arm-shoulder region in discus throw. Using a lighter
459 discus can add some variability in the sequencing and intensity of muscular activation mainly
460 during the delivery phase, which is the most physically demanding phase for upper limbs.
461 Whether this variability is sufficient to reduce the physical load on muscles and joints thus
462 limiting the occurrence of injury remains to be confirmed with longitudinal intervention
463 studies. Coaches and practitioners can use these data to enhance their knowledge of the
464 discipline and implement more specificity in training for their athletes. These data can also
465 help physicians and physiotherapists optimise their rehabilitation protocols for injured
466 athletes. Injury prevention programs should also focus on the throwing phases with highest
467 muscle activity. Although valuable sEMG and kinetic data were obtained during several
468 discus throws performed by elite athletes in ecological conditions, it is important to consider
469 the limitations of the present results. **MVIC of each muscle considered for analysis was**
470 **obtained by using manual muscle testing. Although this method was chosen for its practicality**

471 in the context of elite sport, it might not reflect the exact maximal isometric force production
472 capacity compared with an isometric ergometer. Recording sEMG data during a dynamic
473 movement can generate artefacts in the signal due to high speed movements and movements
474 between the muscles and the electrodes. Another limitation of the study is that the sEMG
475 analysis was restricted to the main muscles of the shoulder-arm region activated during the
476 throw and deemed the most susceptible to injury.⁷ Future research should extend the analysis
477 to more muscles (mainly of the rotator cuff region) and an examination of the mechanical load
478 applied to the tendons during the throw.

479

480 **CONCLUSION**

481 The results of the current study indicate slight differences in muscle activation of the arm-
482 shoulder region between discus throws performed with a standard (2.0kg) and lighter (1.7kg)
483 discus in elite throwers in ecological conditions. These changes in muscle activation likely
484 reflect a higher variability in muscle activation pattern of the throwing arm by using a lighter
485 discus as no marked increase or decrease in muscle activation was noticed. Throwing kinetics
486 and performance were also altered by using a lighter discus as the discus speed increased at
487 release as well as the throwing distance, confirming the importance of a high discus speed at
488 release to attain high performance. The results also suggest that a lighter discus could be used
489 during pre-competitive training to add variability in muscle activation and thus limit the
490 overload on certain muscles of the arm-shoulder region. The next stage of research should
491 focus on the potential of using lighter discs to reduce the mechanical load applied on the
492 tendons of the shoulder-arm region.

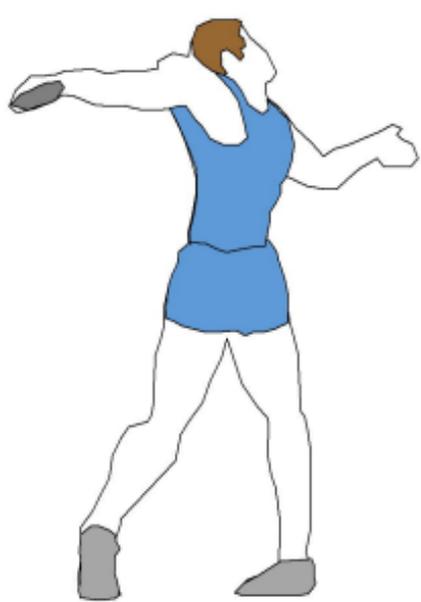
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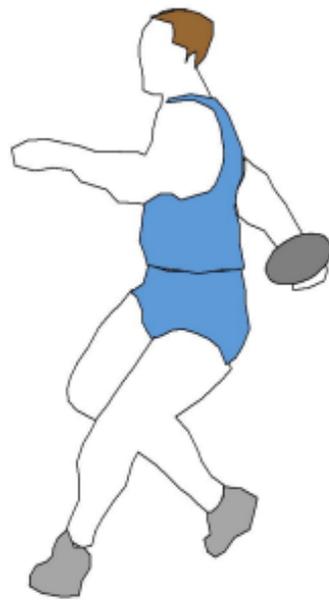
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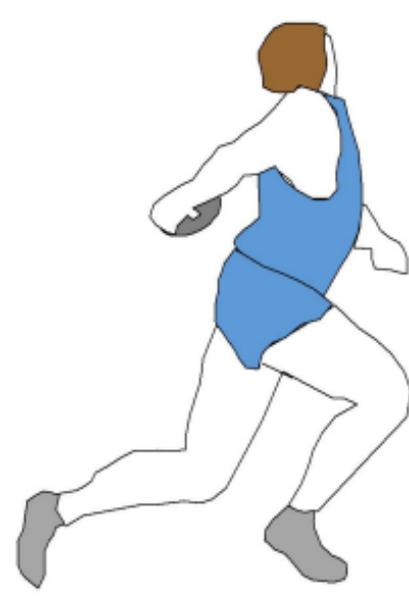
a)

Preparation
P1



b)

Entry
P2



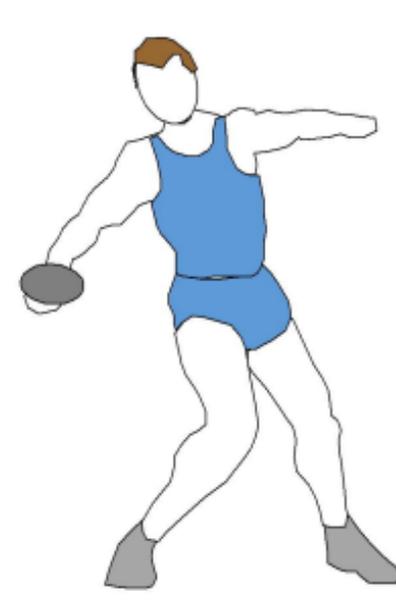
c)

Airborne
P3



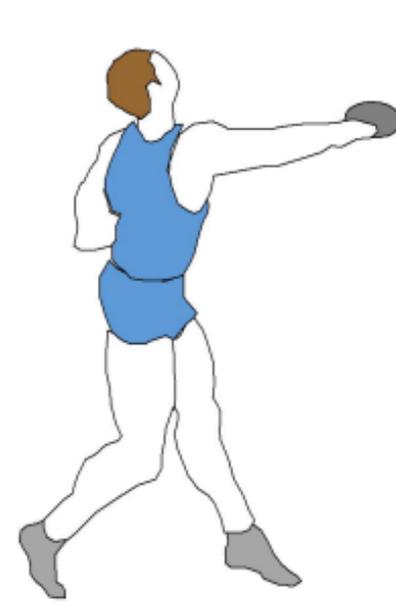
d)

Transition
P4



e)

Delivery
P5



f)

Figure 1: Discus throwing phases (P1 to P5) and critical transition points (a to f) preceding each phase for a right-handed athlete, adapted from Yu et al. ² P1) Preparation, a double support phase starting from the change in discus direction at the end of its backward swing and ending when the right foot breaks contact. P2) Entry, a single support phase which finishes with the left foot breaking contact. P3) Airborne, which finishes with the right foot re-contacting; P4) Transition, a single support phase which ends as the left foot lands; P5) Delivery, which starts as a double support phase and which ends at the release of the discus. a) Start of discus trajectory, b) right foot takeoff, c) left foot takeoff, d) right foot touchdown, e) left foot touchdown, and f) discus release.

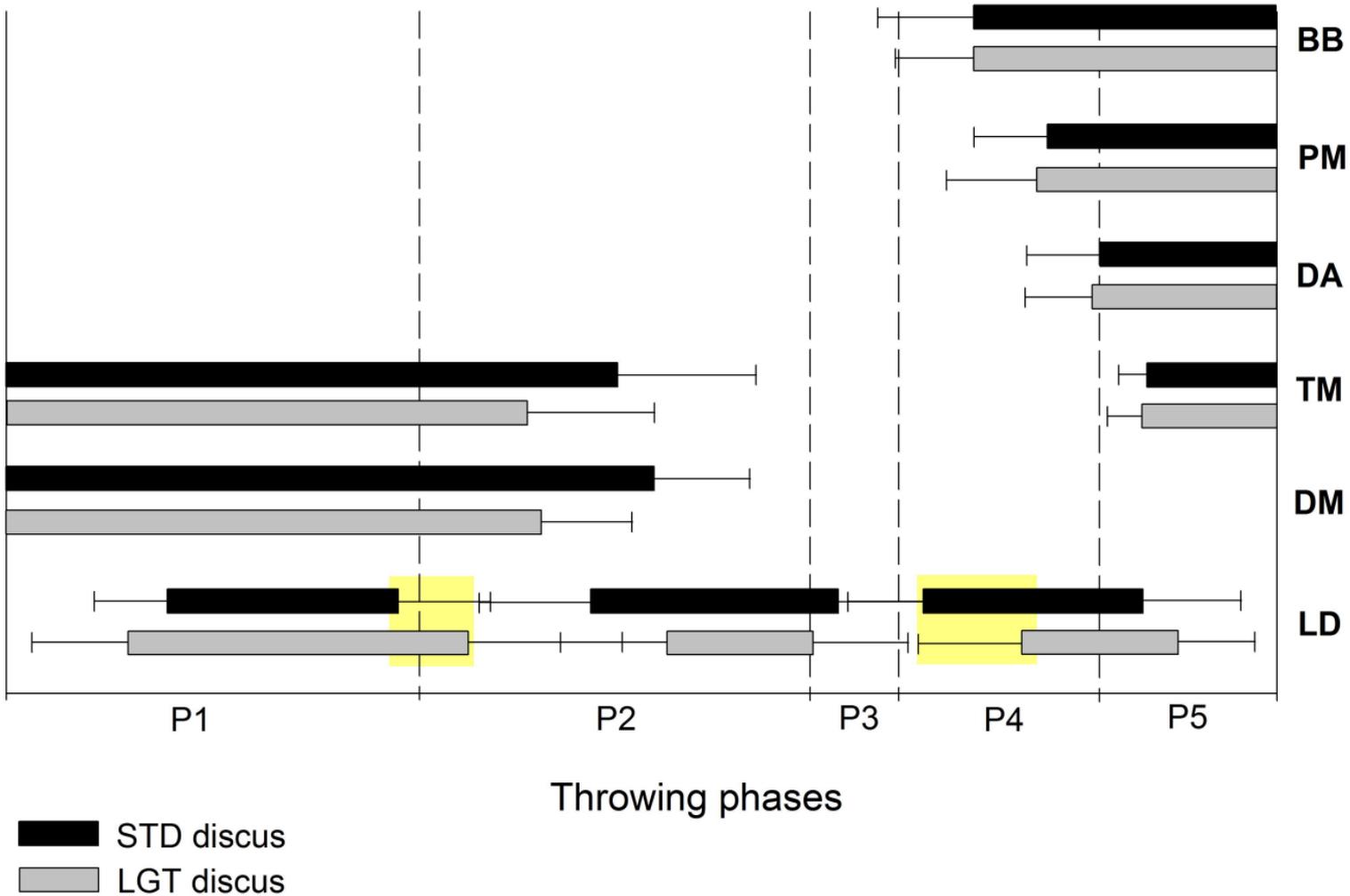
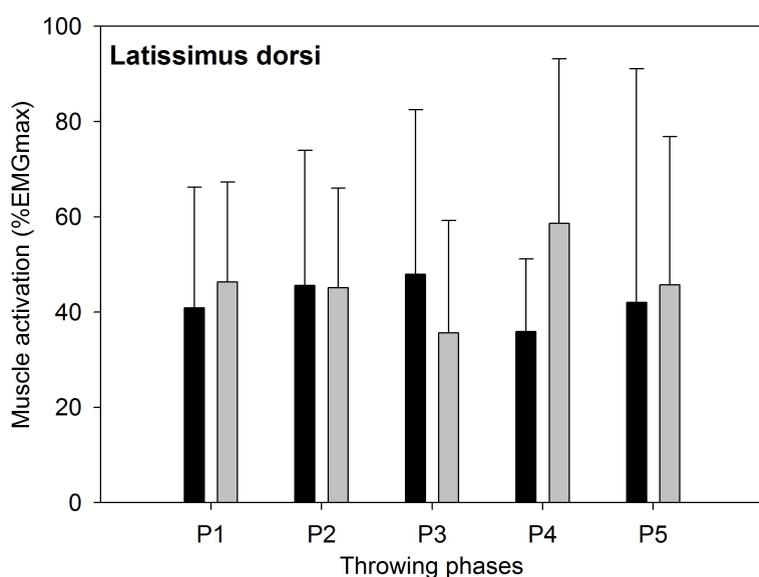
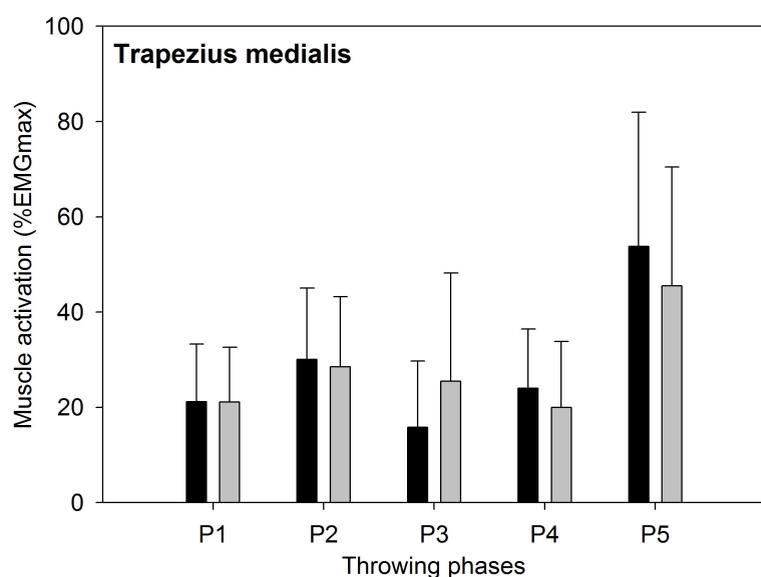
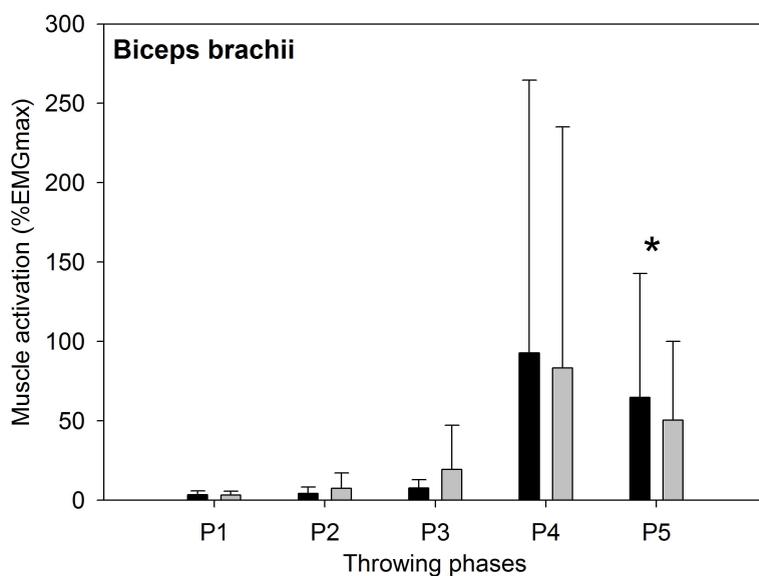
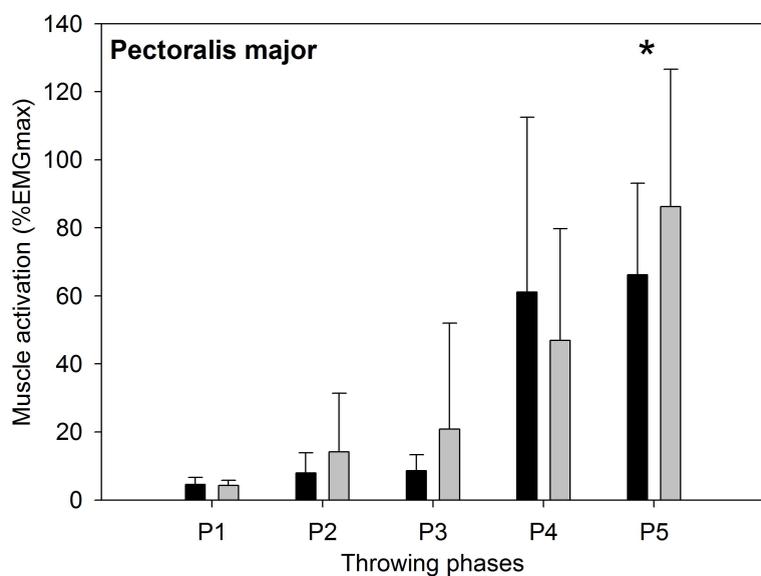
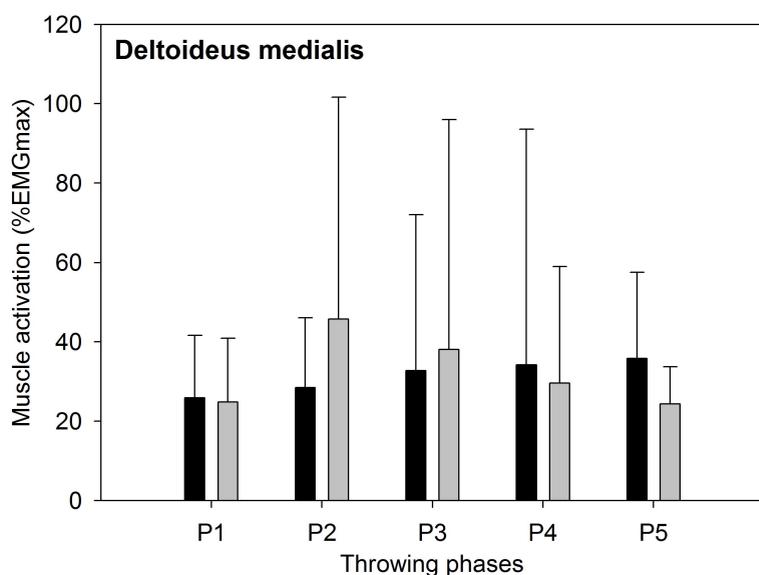
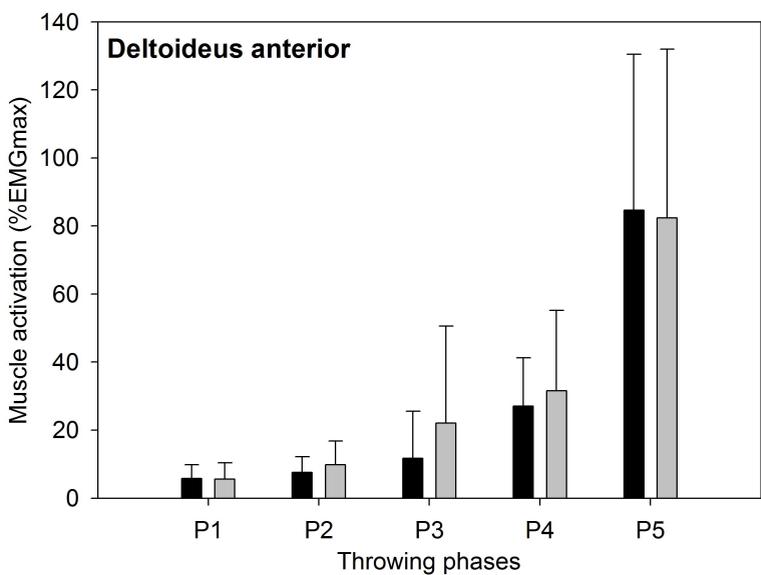


Figure 2: Temporal muscle activation pattern (%EMGt) of muscles of the throwing arm-shoulder at different phases of the throw and with the different discs (STD vs LGT discus). Throwing phases are defined as: P1: preparation; P2: entry; P3: airborne; P4: transition; P5: delivery. Muscles are defined as: BB: biceps brachii; PM: pectoralis major; DA: deltoideus anterior; TM: trapezius medialis; DM: deltoideus medialis; LD: latissimus dorsi. The yellow shapes indicate a significant difference ($P < 0.05$) between throwing conditions (STD vs LGT discus).



for all graphs :

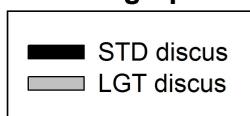


Figure 3: Intensity of muscle activation (%EMGmax) during each throwing phase and for both conditions (STD vs LGT discus). P1: preparation phase, P2: entry phase, P3: airborne phase, P4: transition phase, P5: delivery phase. * Significant difference ($P < 0.05$) between throwing conditions (STD vs LGT discus).

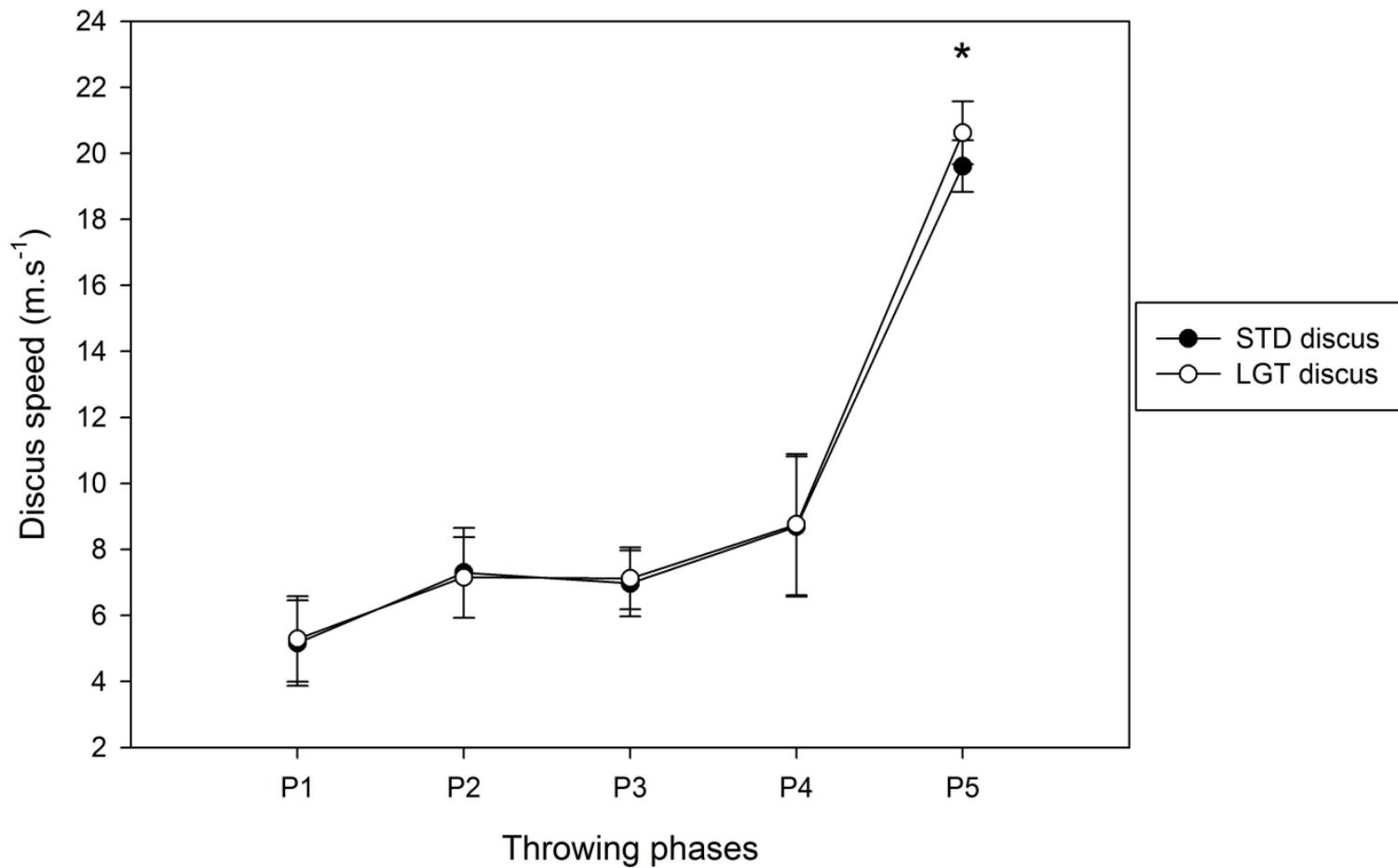


Figure 4: Comparison of discus speeds between throwing conditions (STD vs LGT discus).

P1: preparation phase, P2: entry phase, P3: airborne phase, P4: transition phase, P5: delivery phase. * indicates a significant difference ($P < 0.05$) between throwing conditions (STD vs LGT discus).

Table 1: Comparison of kinetic and performance variables during the delivery phase (P5) of discus throws between the two throwing conditions (STD vs LGT discus). CoM, centre of mass). * indicates a significant difference ($P < 0.05$) between throwing conditions (STD vs LGT discus).

	STD discus	LGT discus
Distance of discus throws (m)	39.38 ± 3.43	43.16 ± 4.27 *
Discus angle ($^{\circ}$)	36.41 ± 3.91	36.05 ± 3.23
Discus height (m)	1.65 ± 1.20	1.69 ± 0.50
Discus speed ($\text{m}\cdot\text{s}^{-1}$)	19.61 ± 0.57	20.62 ± 0.75 *
Speed of the CoM ($\text{m}\cdot\text{s}^{-1}$)	1.47 ± 0.39	1.43 ± 0.36