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Effects of a lighter discus on shoulder muscle activity in elite throwers, implications for injury prevention

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

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

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ABSTRACT

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

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

Study design: Case-control laboratory study

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

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

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

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

Levels of Evidence: Level 3

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

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

What the study adds to existing knowledge: Discus throwing requires a specific muscle activation sequencing throughout the different phases of the throw. Muscle activation is the highest during the last part of the throw, namely the delivery phase, which involves an acceleration of the throwing arm to increase the release speed of the discus. Stabiliser muscles are also almost constantly active during the throw to maintain the discus height and allow a better transfer of the forces and torques from the lower to upper limbs. Using a lighter discus during certain training sessions may help lower the mechanical load on muscles and tendons of the shoulder region by adding some variability in the pattern of muscle activation. Based on these new data, injury prevention and rehabilitation processes should also focus on the phases with the highest muscle activity.

INTRODUCTION

Discus throw requires technical and physical skills to perform complex movements at high speed in a restricted area.[1-3] Performance in discus throw is measured by official distance and mainly depends on the maximum speed, optimum height and specific angle of the discus at release.[1,4,5] Detailed analysis of the discus throw is generally carried out by subdividing the motion into five consecutive phases (figure 1): i) 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; ii) entry, a single support phase which ends with the left foot breaking contact; iii) airborne, which ends with the right foot re-contacting; iv) transition, a single support phase which ends as the left foot lands; v) delivery, which starts as a double support phase and ends at release of the discus.[1-3] Each phase has a different influence on the final throwing performance.[2,5] Angular momentum of the discus in horizontal and vertical components increases during the preparation and entry phases. The ground reaction forces applied on the subject's feet during the entry phase increase the forward speed of the thrower-discus system.[2] The loss of discus speed needs to be reduced using an optimal duration of airborne phase.[4] The ground reaction forces applied to the subject's feet during the last two phases (transition and delivery) are also significantly correlated with the final performance.[2] Finally, the majority of horizontal and vertical velocities are increased by the thrower during the delivery phase.[4,6] According to Yu et al.[2], lower limbs support important loads during the different phases of entry, transition and delivery. Indeed, a positive correlation was found between the increase in vertical speed from the foot opposite to the throwing arm and the official distance. As such it is well known that performance in discus throwing is strongly influenced by the activity of lower limbs. On the contrary little information is known on the physical load applied to upper limbs which yet drive the discus during the entire duration of the throw.[3,5]

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

As reported in other throwing sports such as handball[12] and shot put[13], training with a lighter ball or weight could improve the athlete's ability to throw at a faster arm speed. Similarly, it can be hypothesized that training with a lighter discus could be used as a training strategy to diminish the physical load during key periods of training, whilst acquiring new abilities. Training with a lower discus mass of 1.7 kg is often used by lower level and young athletes in order to improve their throwing motion abilities. To the best of our knowledge, only one preliminary study focused on the utilisation of different discus masses on the body kinematics of three male and two female elite discus throwers.[14] Results suggested that only the discus speed at release time was influenced by the discus mass, with no alteration of body kinematics during the throw.[14] However, potential changes in muscular patterns and coordination during each phase of the throw were not investigated. Improving the knowledge of muscle activation patterns during the specific phases of discus throw would allow a more specific strength and conditioning preparation to help improve performance, reduce the risk of injury and optimise rehabilitation processes.

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

METHODS

Study design

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

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

Participants

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

Surface electromyography procedure

All testing was carried out in the outside throwing area where the athletes use to train on a daily basis. The surface EMG (sEMG) activity was recorded using bipolar self-adhesive surface electrodes (Blue Sensor M-OO-S Medicotest, France). These pairs of 1g-AgCl pre-gelled electrodes (centre-to-centre inter-electrode distance of 2 cm) were applied on the palpated belly of the 6 muscles in parallel with the muscle fibres at the midportion of each muscle according to Seniam recommendations.[15] In order to reduce impedance (<5kΩ) at the interface between the skin and the surface electrodes, the participant's skin was prepared by removing hair from the tested area, followed by light skin abrasion and alcohol cleaning. The electrodes were secured with surgical tape and cloth wrap to minimize disruption during movement.

Surface electromyography normalizing procedure

Prior to sEMG recordings, participants performed a 15min discus throwing specific warm-up under supervision of the national coach. sEMG signals during maximal voluntary isometric contractions (MVIC) were then collected as reference for normalization procedure.[16,17] To determine the maximum sEMG signal for the 6 muscles of the shoulder and arm regions, three isometric contractions were performed and maintained for 3 to 5s.[18] Prior to the three maximal attempts, the athletes were familiarized with the procedure and asked to produce a series of submaximal and gradually increasing contractions. The MVIC were then performed according to the procedure described by Knudson and Blackwell[19] and recently used by Henning et al. [20] in softball players. Two sport physiologists administered the resistance by manual exertion while a third assistant helped them by fixing the proximal body segment. Participants were then instructed to produce a maximal effort in opposition to the external resistance. Manual muscle testing was performed as follows: for DA and PM, participant stood, arm extended and in 90° abduction in the frontal plane and 30° anterior flexion in the sagittal plane, thumb oriented upward. The investigators applied a backward force onto the wrist in the antero-posterior axis. For BB, participant stood, arm along he body with a 60° elbow flexion in the sagittal plane with the forearm in supination. The investigators applied a downward resistance onto the wrist in the vertical axis. For DM, participant stood, arm extended and in 90° abduction in the frontal plane and with a 30° anterior flexion in the sagittal plane. The thumb was oriented upward. The investigators applied a backward resistance onto the wrist in the vertical axis. For TM, participant sat upright on a bench with a 90° knee flexion, arm extended along the body. The investigators applied a downward resistance onto the wrist, in the vertical axis. For LD, the participant was lying prone with the arms resting at the sides. The participant was asked to internally rotate the arm so that the thumb faced towards the ground and raise it up away from the table into extension. The investigators applied a force on the forearm in the direction of abduction and flexion. Participants rested for 1 min between each contraction.[19,21,22] The best performance consecutive to the three trials determined the MVIC and was kept for the analysis.

General procedures

After completing the discus throwing specific warm-up and MVIC procedures, athletes went to the throwing area and were instructed to perform twelve maximal discus throws according to the criteria of realisation of the International Association of Athletics Federation (IAAF). Six throws were performed using a standard 2.0kg competition discus (STD discus). The six other throws were performed using a lighter 1.7kg discus (LGT discus). A passive 3min recovery period was set between each throw to avoid cumulative muscular fatigue. The order in which the discs were tested was randomized. The five best throws performed with the STD and LGT discus were retained for analysis, allowing one bad/adjustment throw per condition. These throws were higher than 80% of the athletes' personal best performance distance. The measured distance of the discus throw was calculated by using the release speed, height and angle of the discus according to the method described by Chow and Mondock.[23]

Video recording and motion analysis

Each throw was recorded using three digitals camcorders (Panasonic AG-455, 50 Hz). These camcorders were located behind the throwing area and on both sides of the discus release area with a 120° angle between each camcorder. The camcorders were placed 3m from the centre of the discus release area. A calibration frame (2m x 2.5m x 2m) with 12 calibration points was set out on the throwing area and used for spatial reference.[24] Each throw was recorded from the instant the athlete began his double support phase starting from the change in discus direction at the end of its backward swing until the end of the delivery phase. Additionally, as described and depicted in figure 1, each throw was divided into 5 phases for a precise sEMG and motion analysis during the entire throw: P1: preparation phase, P2: entry phase, P3: airborne phase, P4: transition phase, P5: delivery phase.[2] Seventeen reflective markers were identified on the thrower's right and left sides: the toes, the lateral malleolus, the lateral epicondyle, the iliac spine, the acromion, the radial epicondyle, the stylion, the 3rd metacarpal, the vertex of the head. One specific marker was placed on the discus geometrical centre. All markers were manually digitized using a video data acquisition system (3D Vision, Biometrics SA, France®). Direct linear transformation method was used to calculate the markers' position in space.[25] Maximal error of the markers' position[26], based on the length of the right forearm was 0.35cm. Data was filtered with a zero phase four-order Butterworth filter. Cut-off frequencies were 12Hz.[5] The marker's positions associated with anthropometric data were used to determine the trajectory of the centre of mass (CoM) of the subject-discus system. Each component of speed (VCoM) of the subject-discus system was computed. The discus absolute speed was computed during each phase and at release time according to Chow and Mondock.[23] The video data was synchronized with sEMG recordings during the entire protocol using the same A/D converter so that motion analysis, sEMG activity, discus speed and distance data were collected simultaneously during the entire protocol.

Surface electromyography data processing

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

Statistical analysis

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

RESULTS

Comparison of the temporal muscle activation between discs

The muscle activation patterns (EMGt) of the shoulder-arm region of the throwing arm are displayed in figure 2. Overall, the temporal analysis of sEMG signals revealed a similar activation pattern with the STD and LGT discs during the discus throw. Three muscle activation periods were detected; the first at the initiation of the movement (phases P1-P2) during which the trapezius medialis, deltoideus medialis and latissimus dorsi were activated; the second situated in the middle of the throw (P2-P3) with the activation of the latissimus dorsi; the third at the end of the throw (P4-P5) with the activation of the biceps brachii, deltoideus anterior, pectoralis major, trapezius medialis and latissimus dorsi.

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

Comparison of the intensity of muscle activation between discs

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

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

Kinetic and performance variables

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

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

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

DISCUSSION

The aim of the present study was to compare the EMG activation patterns of muscles from the arm-shoulder region at different phases of the discus throw when using a STD and LGT discus. It was hypothesized that when performing throws with the LGT discus, the muscles of the throwing arm-shoulder region would display a lower EMG activation compared to throws performed with a STD discus. The study also aimed to investigate the potential alteration in motion kinetics of the discus-thrower system and performance variables.

Differences in muscle temporal activation between discs

The results from the current study show that the temporal activation pattern of muscles from the arm-shoulder region were almost identical when using the STD and LGT discus. Only the temporal activation of LD was significantly altered during the first (in P1-P2) and last activation periods (in P4-P5) with the LGT discus. This result suggests that the distribution of muscle activation through the different phases of discus throwing was robust enough to resist to changes in discus mass in elite throwers, thus partly rejecting the initial hypothesis. Limiting the variability of the kinematics and muscular pattern has been associated with a better efficiency in discus throw.[5] The thrower may try to coordinate their own muscular contractions in order to use a motor program adapted to their skills.[5,28] Besides, an understanding of muscles at work during the different phases throughout the throwing cycle allows for a better assessment of the mechanical load imposed by the sport. As displayed in figure 2, discus throwing requires an almost constant muscle activation of stabiliser muscles (LD, DM, TM) during the whole movement. This specific muscle activation sequencing is suggested to be a prerequisite to stabilise and accompany the throwing arm towards the greatest release speed with the optimal discus angle at release. It is also suggested that maintaining the discus height constant during the whole movement until the delivery phase reflects the ability of the best athletes to reproduce the same motor performance to provide optimum conditions for delivery.[4] Even though the current study is the first to report temporal muscle activation in discus throwing making comparisons with other studies difficult, it is well known that the duration of the different throwing phases is very consistent at elite level.[4,29] The longest parts of the throw are reported to be the preparation phase (P1) and entry (P2) during which stabiliser muscles are the most activated. The entry phase is then followed by the airborne phase (P3) of very short duration in order to minimise the loss of discus speed (figure 2). The goal of the thrower during this phase is to initiate the separation of the hip axis over the shoulder axis and of the latter over the discus. As such, P3 marks the transition between the activation of stabiliser and effector muscles. This hip-shoulder separation required to increase the discus speed is then mainly obtained during the transition phase (P4) during which the BB and PM muscles are activated. BB and PM muscles allow the horizontal adduction/forward swing of the throwing arm till the delivery phase (P5), while the DA and TM facilitate the opening of the release angle for delivery.

Differences in intensity of muscle activation between discs

The analysis of the intensity of muscle activation (expressed as percent of maximal activity during MVIC) provides more details on the understanding of the muscular solicitation required to perform in discus throw. The first finding is that using a lighter discus slightly modified the activity of PM and BB only during the delivery phase when they are the most activated to place the throwing arm in the best condition for discus release. The activity of PM was increased by 20% by using the LGT discus compared to STD, while the activity of BB was lowered by 15% with the LGT discus. Even though these results were significant it seems important to consider the large inter individual variability of EMG data (figure 3). As such it can be hypothesised that the differences in EMG activity recorded between LGT and STD conditions might reflect normal muscular and biomechanical adjustments of the athletes. This result is in agreement with Peng and Huang[10] and the data from Finanger's doctoral thesis[30] presented by Bartlett[4] where the variability of EMG activity was the greatest for the BB.

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

The LD, TM and DM presented a constant medium to high EMG intensity during the entire throw confirming their role of stabiliser muscles. More specifically, the LD presented the highest activity with EMG values ranging from 35 to 60% of EMGmax during the entire throw. These data show the great stress placed on the active stabilisation and control of body kinematics during the entire throw. As such, stabiliser muscles could also be exposed to excessive fatigue and even overuse in discus throwing. In addition, weaker stabiliser muscles may fail to contain the shoulder joint and position of the throwing arm, thus exposing the rotator cuff to excessive mechanical load to compensate for this. Consequently, overuse, fatigue tendinitis, rotator cuff tear or impingement may occur.[32]

Differences in motion kinetics and performance between discs

In addition to muscle activation levels, this study also investigated the motion kinetics and performance variables between the discs tested. The results of the study confirm that the discus speed significantly increases during the delivery phase (P5) and in greater proportion when using the LGT discus. As demonstrated in previous publications, the majority of the horizontal and vertical speeds are obtained during the delivery phase.[1,4] Between 62% and 73% of the release speed of the discus could be generated during the delivery phase.[4] Higher performances are also commonly associated with higher release speeds. As such release speed is reported to be the most influential determinant of the distance of the throw and the emphasis in training should be brought on the attainment of a high discus speed at release. As suggested by our results, using a lighter discus during training could serve this purpose by allowing for a greater acceleration of the throwing arm from the second double support phase initiated at the beginning of P5 (figure 4). While non-significant, the speed of the centre of mass in P5 was reduced by using the LGT discus which could contribute to the attainment of a greater acceleration of the throwing arm. Indeed, according to Susanka et al.[29], a rapid achievement of the double support position with a stable and open delivery stance would represent optimal conditions to reach maximal acceleration. On contrary to discus speed, the angle and height of the discus at release were not modified by the discus mass between throws. The majority of the studies have reported large variations in discus height between throwers which is largely dependent on the thrower’s height. With regards to the angle of the discus at release, optimal angles range from 35 to 44° which is in agreement with our results.[4] However the release angle may be influenced by the physical and technical characteristics of the thrower and the wind conditions, head winds forcing the athletes to reduce the release angle whereas tails winds could increase the angle.[4,6] In the end, discus speed, height and angle at release, should be optimised to maximise the discus spin and provide sufficient gyroscopic stability for a long trajectory. In our study, the mean distance covered by the discus after release was greater by using the LGT discus (43.1 ± 4.3 m) compared to STD (39.4 ± 3.4 m) confirming that increasing the release speed is likely the most important parameter for high performance in discus throw.

Practical applications and limitations

These data provide new evidence of the sustained mechanical load applied on both stabiliser and effector muscles of the arm-shoulder region in discus throw. Using a lighter discus can add some variability in the sequencing and intensity of muscular activation mainly during the delivery phase, which is the most physically demanding phase for upper limbs. Whether this variability is sufficient to reduce the physical load on muscles and joints thus limiting the occurrence of injury remains to be confirmed with longitudinal intervention studies. Coaches and practitioners can use these data to enhance their knowledge of the discipline and implement more specificity in training for their athletes. These data can also help physicians and physiotherapists optimise their rehabilitation protocols for injured athletes. Injury prevention programs should also focus on the throwing phases with highest muscle activity. Although valuable sEMG and kinetic data were obtained during several discus throws performed by elite athletes in ecological conditions, it is important to consider the limitations of the present results. MVIC of each muscle considered for analysis was obtained by using manual muscle testing. Although this method was chosen for its practicality in the context of elite sport, it might not reflect the exact maximal isometric force production capacity compared with an isometric ergometer. Recording sEMG data during a dynamic movement can generate artefacts in the signal due to high speed movements and movements between the muscles and the electrodes. Another limitation of the study is that the sEMG analysis was restricted to the main muscles of the shoulder-arm region activated during the throw and deemed the most susceptible to injury.[7] Future research should extend the analysis to more muscles (mainly of the rotator cuff region) and an examination of the mechanical load applied to the tendons during the throw.

CONCLUSION

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

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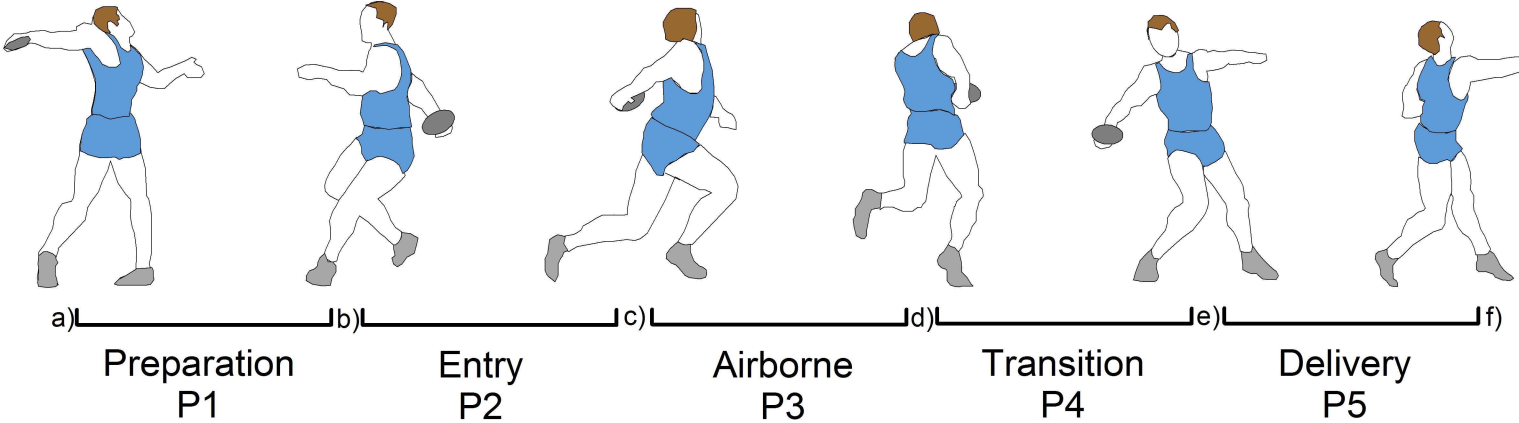

a)
b)
c)
d)
e)
f)
Preparation
P1
Entry
P2
Airborne
P3
Transition
P4
Delivery
P5

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.

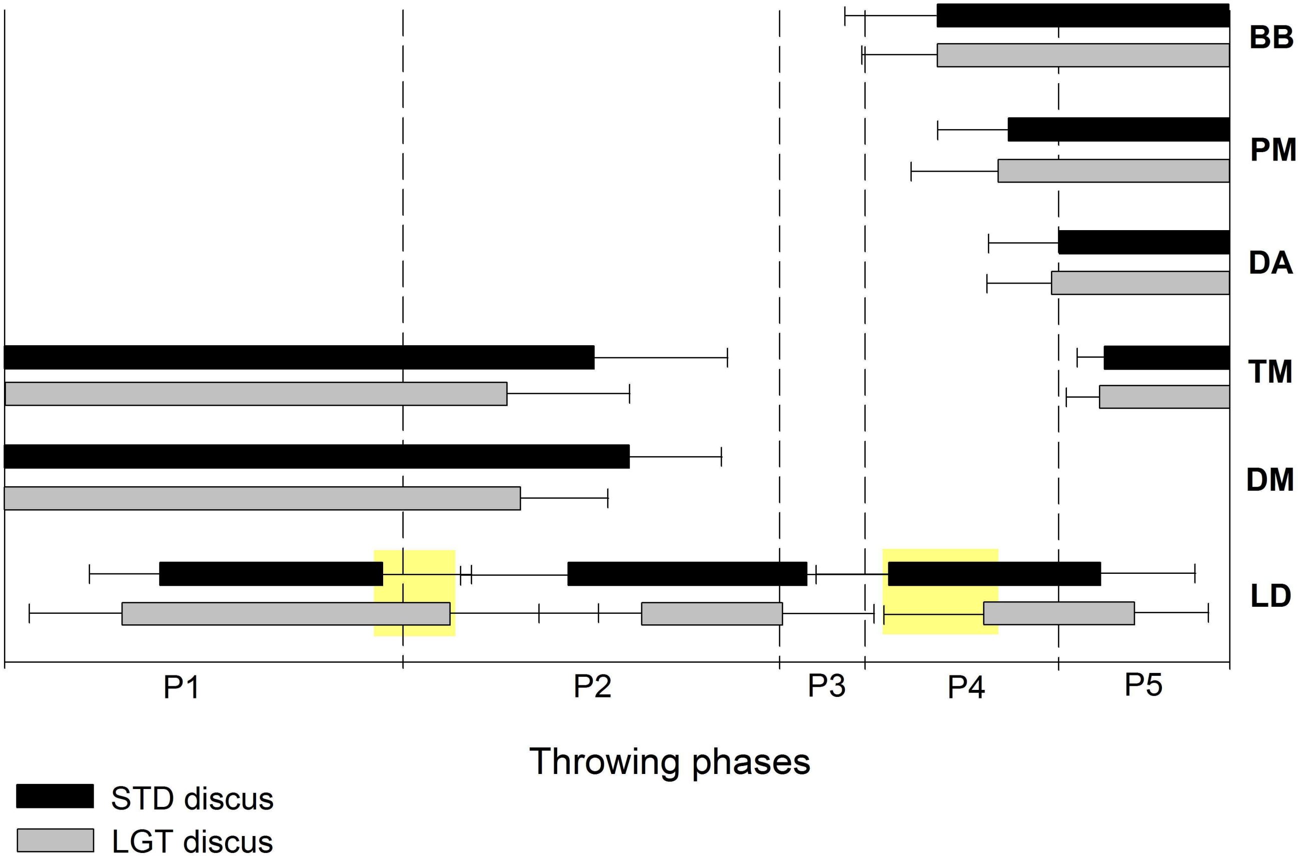

BB
PM
DA
TM
DM
LD
P1
P2
P3
P4
P5
Throwing phases
STD discus
LGT discus

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: airbone; 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).

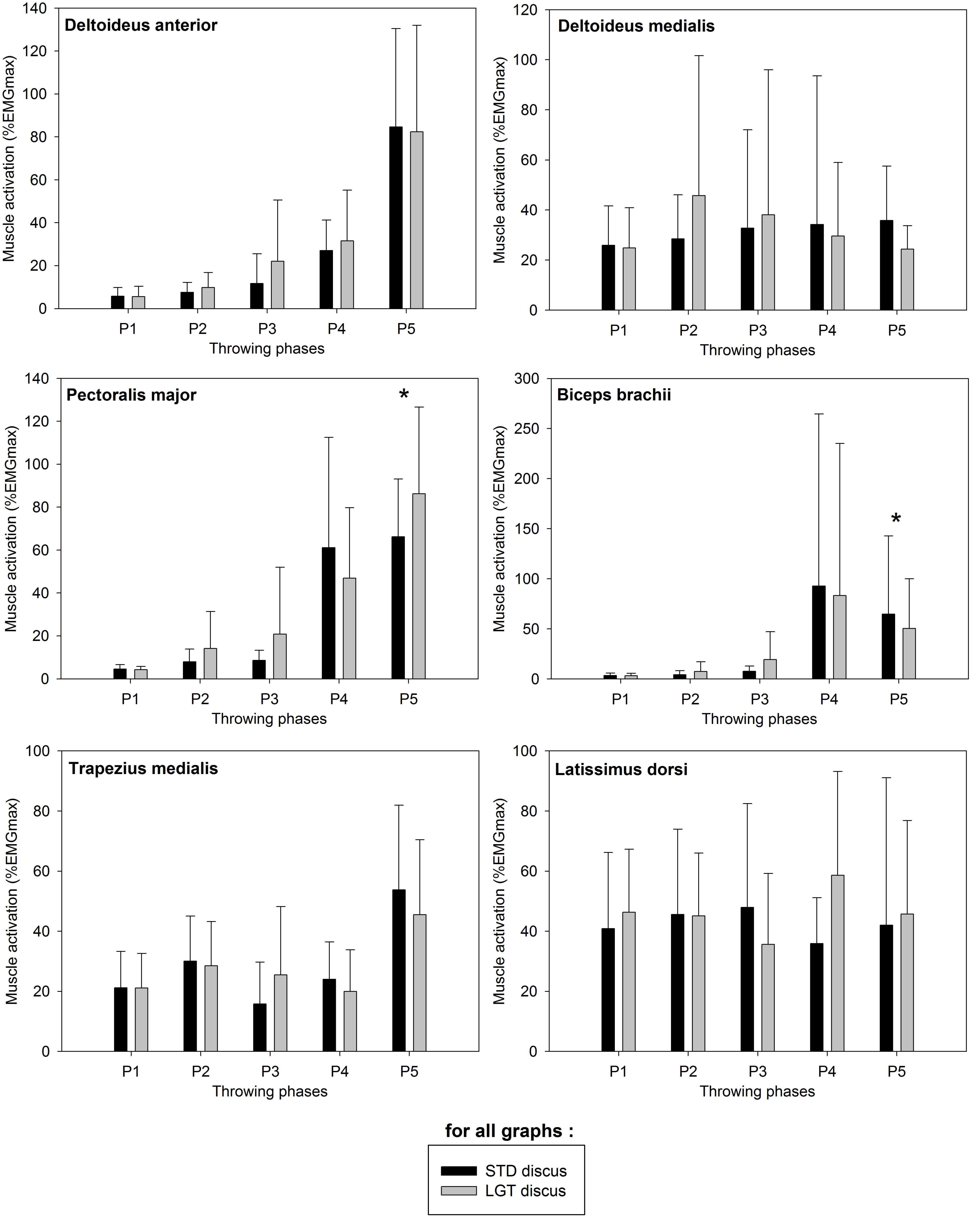
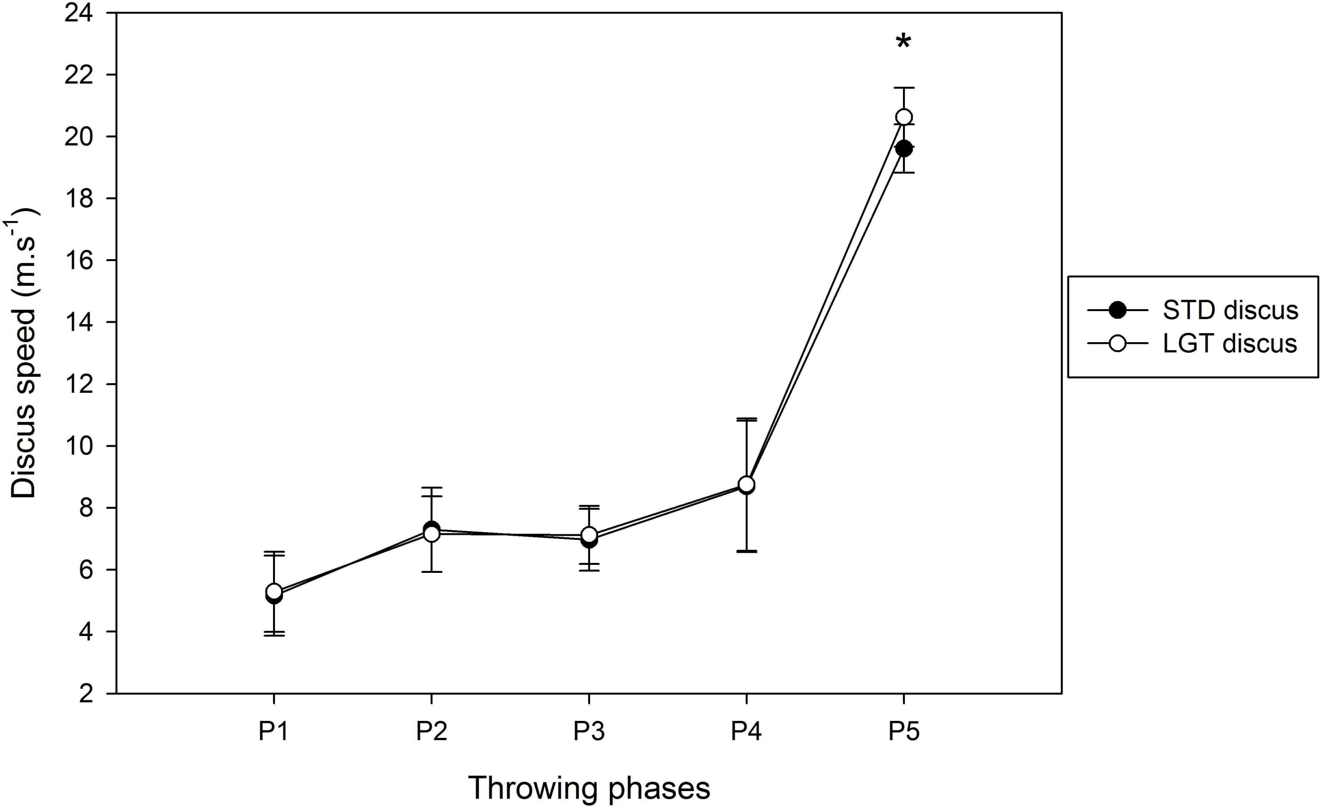

Deltoideus anterior
Deltoideus medialis
Pectoralis major
Biceps brachii
Trapezius medialis
Latissimus dorsi
*
*
Muscle activation (%EMGmax)
Throwing phases
P1
P2
P3
P4
P5
0
20
40
60
80
100
120
140
150
200
250
300
for all graphs :
STD discus
LGT discus

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).



Discus speed (m.s^{-1})
24
22
20
18
16
14
12
10
8
6
4
2
P1
P2
P3
P4
P5
Throwing phases
*
STD discus
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 (°)	36.41 ± 3.91	36.05 ± 3.23
Discus height (m)	1.65 ± 1.20	1.69 ± 0.50
Discus speed ($m.s^{-1}$)	19.61 ± 0.57	20.62 ± 0.75 *
Speed of the CoM ($m.s^{-1}$)	1.47 ± 0.39	1.43 ± 0.36