THE INFLUENCE OF DISCUS MASS ON PERFORMANCE-DETERMINING VARIABLES

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The purpose of this study was to investigate the effects of discus mass on two performance-determining variables; timing of acceleration and release velocity. Twelve male discus throwers performed 25 throws with 5 different masses as inertial sensors collected acceleration data of each throw. Release velocity, but not timing of acceleration, was influenced by discus mass. Large differences were seen between skilled and less skilled athletes with regard to timing of acceleration and release velocity. Skilled athletes demonstrated altered timing of acceleration with increased discus mass. No such differences, however, were found between more and less powerful athletes. As a result, the less skilled athletes were more affected by the varying discus mass than the skilled athletes.

KEY WORDS: discus throwing, inertial sensors, specific resistance training.

INTRODUCTION: Discus throwing is a technical and physically demanding event in athletics that requires the athlete to perform high-speed rotational movements in a limited space (Dai, Leigh, Li, Mercer, & Yu, 2013). Factors that have been shown to predict superior performance include a large discus release velocity. Technical aspects that are shown to increase the release velocity are torsion between the hip, trunk, and shoulder, discus placement related to the body, and proximal-to-distal acceleration timing (Barlett, 1992; Leigh, Gross, Li, & Yu, 2008). Another way to increase the release velocity is by the overload principle of either force or velocity to enhance the power of the athlete (Van Den Tillaar & Ettema, 2011). This can be done by either a-specific weight training or specific resistance training (SRT). In particular, SRT has been shown to improve athletic performance compared to non-sports specific weight training (Escamilla, Fleisig, Barrentine, Andrews, & Speer, 2000; Van Den Tillaar & Ettema, 2011). SRT uses weighted objects during the actual movement tasks (Szymanski, 2012). Previous research has identified an increase in release velocity when the athletes trained with either a lighter or a heavier version of the actual object in various overhead-throwing tasks such as in baseball, basketball, handball, and the football throw-in (Escamilla, et al., 2000; Szymanski, 2012; Van Den Tillaar & Ettema, 2011). However, it was also shown that throwing kinematics were highly sensitive to weight variation (Van Den Tillaar & Ettema, 2011). If the imposed resistance is inappropriate, it could have an undesirable influence on the athlete’s technique (Escamilla et al., 2000; Lin & Chen, 2012). Furthermore, there may be an increased risk of injury when the loaded object does not fit the physical capabilities of the athlete (Escamilla et al., 2000). For this reason, SRT load should be adjusted for each athlete individually. Although SRT is a commonly used training method for discus throwers, it remains unknown what the influence of either increased or decreased discus inertia are on discus trajectory in the delivery phase or athlete kinematics, which subsequently influence performance. As a result, it is possible that the utilisation of SRT in discus throwing is not optimally applied. The aim of this study was to investigate whether discus mass influences two performance-determining variables: discus release velocity and timing of acceleration between the hip and sternum, where the timing of acceleration is a surrogate for the angle between the hip and trunk. Furthermore, we also investigated whether these variables were dependent on the skill level (personal best) or the leg power level of the athlete. Where the leg power is a surrogate for the general power of the athlete.

METHODS: Twelve male discus throwers (mean age 26.3 +/- 4.6 years) volunteered to participate in this study and signed an informed consent. All participants were trained discus throwers in the top 20 of the Dutch national ranking list of 2014 and had experience throwing discs of various masses. Five synchronised 9-degrees of freedom accelerometers measured 3D linear acceleration and 3D angular velocity (500Hz; MPU-9150, Invensense, San Jose, USA). These accelerometers were placed on the athlete's left and right foot, the hip of the throwing arm side, the sternum and on the dorsal side of the throwing hand. After performing warm-up trials, athletes performed five successful competition throws for each discus condition (1.50kg; 1.75kg; 2.00kg, the official discus mass; 2.25kg; 2.50kg) for a total of 25 throws. The athlete was instructed to take a break if he felt fatigued. A successful throw was defined as one where the throw was not halted/aborted by the athlete and all the sensors remained intact. The order of the weight conditions was randomised per participant.
Skill level was defined as the athlete's personal best throw, in meters. The athlete's peak leg power level was calculated from the countermovement jump (CMJ) jump height. The Jump height was measured with the linear acceleration in y-direction from the sensors on the foot ($CMJ_{height}=((9.81*(T_{flight}))^2*100$) and subsequently the power was calculated using the following formula: $p_{peak}=61.9*CMJ_{height} + 36.0*\text{body mass}-1822$, where CMJ was defined as jumped height (cm) and body mass as the mass of the participant (kg) (Harman, Rosenstein, Frykman, Rosenstein, & Kraemer, 1991). This method was validated in pilot testing using the Optojump System. The release velocity was calculated at the moment of discus release with the accelerometer on the hand with: $v = \omega*(0.5*\text{armspan})$ as a surrogate for discus velocity. Where arm span was measured in (m), and ω is the 3D angular velocity vector of the hand sensor.
All data processing was performed using custom-made code in Matlab (MATLAB 8.3, The MathWorks Inc., Natick, MA, 2014). Throw detection was done using the pelvic angular velocity data of the longitudinal y-axis. A fourth order low-pass Butterworth filter with a cut-off frequency of 0.1 Hz was used for throw detection. Timing of acceleration was defined as the moment the hip started to accelerate minus the moment the sternum started to accelerate. A negative value indicated that the sternum started to accelerate before the hip.
Due to the small sample size (N=12), a non-parametric Friedman's ANOVA was conducted to determine whether there were any between-discus mass differences in release velocity or timing of acceleration ($\alpha = .05$) of the atypical weights compared to the official competition weight. When significant results were found, a Wilcoxon signed-rank test with Bonferroni correction was performed to identify which mass conditions differed significantly. To analyse whether the skill level of the athlete influenced performance in the different conditions, the subjects were split into two groups based on personal best (PB greater/less than 55 meters). 55 Meter was chosen because that distance was necessary to win a medal in the dutch championships of 2014. To examine whether the leg power of the athlete influenced the results, the subjects were split into two groups (below/above average leg power). A priori, the split groups were significantly different from each other; for the PB groups (U=32, z=2.717, p<0.01) and for the power groups (U=35, z=2.842, p<0.01). To determine whether there were differences between these groups, Mann-Whitney U tests were performed.

RESULTS and DISCUSSION: The discus release velocity was significantly influenced by the discus mass ($X^2(4)=31.133$, $p<0.001$; Figure 1). Post-hoc tests showed that the average release velocity with the 2.00 kg discus (19.71 m/s) was significantly lower than the release velocity for the 1.50 kg condition (22.2 m/s; z=-2.981, p=0.003). Similarly, the release velocity with the 2.50 kg condition was significantly lower than that of the 2.00 kg condition (17.45 m/s; z=-2.981, p=0.003) (Figure 1). No differences were found between the 1.75 kg compared to the 2.00 kg and 2.25 kg compared to the 2.00 kg weights. These findings confirmed our hypothesis that the heavier weights would be lower in velocity than the lighter weights. The release velocity was determined with the hand sensor as
In contrast, the timing of acceleration between the hip and sternum was not significantly affected by the discus weight when testing all subjects ($X^2(4)=0.267$, $p=0.992$). However, when subjects were split based on their PB, there were distinct differences in the timing of

acceleration (figure 2) (*U*=35, *z*=2.627, *p*<0.01 and *r*=0.76). The higher skilled athletes (PB>55m) showed (although not significant) an increase in the timing of acceleration with increase of discus mass. It seems that the sternum acceleration was delayed due to the increased inertia with the heavier weight. This increase in timing of acceleration was not observed in the less skilled athletes (PB<55), suggesting that the less skilled athletes were more likely to diverge their throwing technique from the proximal-to-distal sequence, which is an undesired effect (figure 2). In line with our results, Martin et al. (2014b) found that professional tennis players were more efficient and had higher ball velocities in the tennis serve compared to less skilled tennis players. The mechanism proposed to cause this difference was a reduced leg drive (disrupted proximal-to-distal sequence of events)

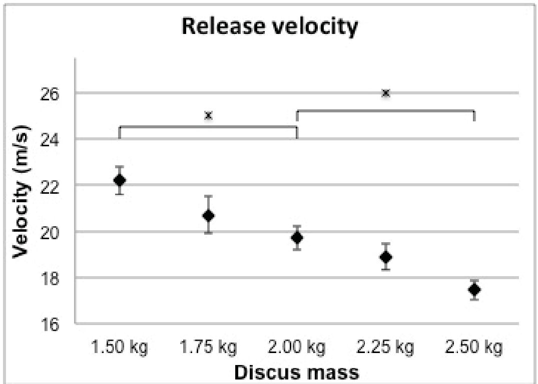

Figure 1: Release velocity averaged over all participants. Error bars indicate standard error of the mean, significant differences (post-hoc tests) indicated with asterisks.

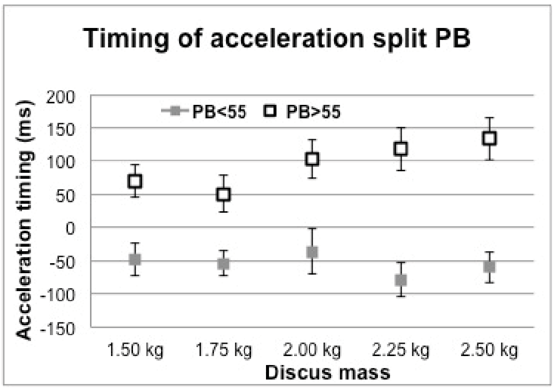

Figure 2: The timing of acceleration with subjects grouped by skill level. Significant differences between the two groups were observed (for all discus masses).

Furthermore, injured athletes also showed a disruption in the proximal-to-distal sequence of events (Martin et al., 2014a). In handball throwing, the timing of hip rotation also demonstrated between-skill level differences (Wagner, H., Pfusterschmied, J., Von Duvillard, S. P., & Müller, E, 2012). In the tennis study, lower release velocities were found in the less skilled athletes compared to the skilled athletes. Similarly, in the current study significant differences in release velocity were observed when the subjects were split according to skill level. The skilled athletes had a higher release velocity with all weights, compared to the less skilled athletes. Since release velocity is the biggest predictor for distance in discus throwing (Leigh, Gross, Li, & Yu, 2008), these results were expected. The observed difference in timing of acceleration may help explain the difference in release velocity.

When we grouped the data by leg power, no significant differences were found between the more powerful athletes and the less powerful athletes, in either release velocity (*U*=12.5, *z*=-0.813, *p*=0.432, *r*=0.23) or timing of acceleration (*U*=14.00, *z*=-0.569, *p*=0.639, *r*=0.16).

Even though power is a predictor for performance, the correlation of these two variables was low (rho = 0.126, p=0.697). This discrepancy could be explained by the large technical skill required to throw a discus, combined with the large variation in personal best between the athletes (range 44.95 m to 61.27 m). Young (2006) indicated that an increase in strength or power does not, by definition, cause an increase in performance. Perhaps this is the case for these athletes, with the most powerful athletes not able to transfer their power to performance as a result of technical inadequacies. Research with a more homogeneous population (e.g., only 60+ throwers) may identify strength and power levels to be a good predictor for throwing performance. Furthermore, due to our small sample size, it is possible that our study is under-powered to test this correlation. Another reason for the small correlation between power and performance may be due to the method used to estimate the power. We estimated power from the CMJ, which is an a-specific movement. Even though previous studies showed that jump height can be correlated with throwing velocity (McCluskey, Lynskey, Leung, Woodhouse, Briffa, & Hopper, 2010) and jump height increases with an increase in lower extremity strength (Channell & Barfield, 2008), jump height fails to measure the inter-muscular coordination pattern necessary for throwing performance. As Young (2006) indicated, general strength does increase performance, but specific strength and inter-muscular coordination patterns are more important in transferring power to performance. Therefore, perhaps a more specific strength test would be a better predictor for the better discus throwers. Future research could investigate whether a more specific power test yields different results.

CONCLUSION: Here we investigated the influence of discus mass on two performance determining variables. Of the two performance-determining variables tested, only release velocity was affected by the discus mass. There were distinct differences between skilled and less skilled athletes with regard to timing of acceleration and release velocity, where the less skilled athletes were adversely affected by the difference in discus mass. No such differences were found between the more powerful and less powerful athletes. Therefore, SRT should be applied with care, considering that the less skilled athletes were more likely to divert from the proximal-to-distal sequence of events, which could lead to more injuries and result in lower performance. For those athletes, technical training would be more useful in gaining the proper technique to increase the release velocity of the discus. Future research should investigate whether diversion from the proximal-to-distal sequence of events may increase injury risk in discus throwers, like it does with tennis players. Additionally, research should focus on how coaches can decide whether SRT will be useful for an individual athlete, and which weight range would be appropriate.

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