Comparison of Shot Put Release Parameters and Consistency in Performance Between Elite
Throwers with and without Intellectual Impairment.

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Abstract

Background. Shot put is one of the events in which athletes with intellectual impairment (II) compete at the Paralympic Games, since their re-inclusion in 2012. The purpose of this study was to compare the competition performance and investigate differences in release parameters and consistency of performance between high level shot-put-throwers with and without II.

Methods. Data collection took place at the 2014 European Championships athletics for athletes with II (n=20; 11 men, 9 women, $M_{IQ} = 60.2 \pm 7.3$, $M_{age} = 28.1 \pm 6.7$ years), and the 2015 national Championships for athletes without II (n= 26, 12 men, 14 women, $M_{age} = 24.9 \pm 5.6$ years). A video camera operating at 100Hz was utilized to capture the throws and 2D images were analyzed with motion analysis software to calculate release parameters and check consistency of the throw.

Results. Independent t-tests revealed that the average (11.87m) and best (14.81m) performance of male world class II-throwers was significantly lower compared to the average (14.62m) and best (17.78m) performance of male national level throwers without II ($F = 5.3$, $p < .05$), primarily due to the significantly lower release velocity ($r = .79$, $p < .01$). The inter-individual variance in throw-to-throw distance was significantly larger in II-throwers; however, opposite to what was expected, the angle of release consistency was not significantly different between both samples. II-throwers performed with superior release velocity consistency than non-II-throwers.

Conclusions. These findings support the assumption that impaired cognitive function might constrain the ability to optimally release the shot-put.

Key words: Consistency, intellectual disability, Paralympic Games, athletics

Introduction

During the Rio 2016 Paralympic Games, new world records were set in the male (16.84m) and female (13.94m) shot put competitions for elite throwers with intellectual impairment (II). The level of competition was of high quality; however, when compared to the Olympic Games one month earlier, the best performance of elite shot put throwers with II was considerably lower; about 30% (male) to 40% (female). It remains currently unknown whether the observed differences in performance are due to: intrinsic factors of the throwers (e.g., body composition, strength), external factors (e.g., training volume, quality of the coaches), their underlying cognitive impairment, or a combination of multiple factors.

The Paralympic Games is the highest obtainable level for II-athletes (1, 2). Evidence-based classification in Paralympic Sport requires evidence for the impact of the underlying impairment on sport specific performance.(3) Performing well in shot put consists of simply throwing the shot as far as possible. The key performance indicators (KPI) determining the length of throw are the explosive strength (4), in combination with anthropometrical factors,(5, 6) along with the long term development of very complex skills, and the ability to perform these complex and precisely timed movements at high velocity in a confined space (i.e., technique). (6-10) Gutiérrez-Davila *et al.* (6) reported that the shot put technique is individual; each thrower uses his or her own individual temporal sequence and rhythm. Apart from the body composition and strength of the thrower, also the degree of automation of the individual temporal sequence determine the optimal individual technique (29). Practice makes permanent and when a fully automated sequence of movements is integrated to efficiently transfer from proximal to distal strength and velocity; the athlete will be able to perform maximally. It is currently not clear if athletes with II have the innate potential (e.g., body schema, body perception) to develop these complex skills to a fully mature skill proficiency level, or if their impairment will constrain the development of optimal

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performance, no matter how hard they train. Therefore, the present study will also focus on the consistency in performance between subsequent throws.

The interdependency of the factors that determine the length of the throw is closely related to the anthropometrical, muscular and technical characteristics of the thrower. (6) An optimal combination of power, body composition and skill proficiency of the thrower results in optimal release parameters (i.e., the angle of release, height of release and release velocity). (6, 9-12) Several studies confirmed that the release velocity is the most important factor. (10, 12) Able-bodied world-class shot-putters have release velocities between 12.5 m/s and 14.5 m/s. (10, 13, 14) The release angle is considered less important than the release velocity; however, substantial deviations from the optimal release angle can adversely affect the outcome. (10) No agreement was found in literature regarding the magnitude of the optimal release angle, mainly because the optimal angle depends on individual differences, for example: gender, height and strength of the thrower. (7)

Despite the huge body of literature investigating how physical and technical components individually contribute to optimal performance in shot put throwers without II, (6, 8, 9, 12, 13, 15) until now, only one study included world-class shot put throwers with II. (16) The results of that study by Willwacher, Potthast, Müller, and Brüggemann (16) demonstrated a significant reduction in the acceleration path of the shot and lower release velocities in throwers with II. The major limitations of the approach used in that pilot study were the limited number of throwers with II ($n=6$), the limited number of analyzed throws (one per athlete), and the lack of a control sample for comparison.

It is the aim of the present study to investigate whether or not having an II is related to performance and consistency of performance in shot put. Three research objectives will be investigated. Firstly, how far high level shot put throwers with II can throw compared to throwers without II during competition, whereby II-throwers are expected to throw

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significantly less far. Secondly, the differences in release parameters are investigated between a sample of elite shot put throwers with II and a non-II-control group of throwers with comparable training volume. It was hypothesized that the II-throwers have a lower release velocity and throw at a different angle of release compared to non-II-throwers. No differences in height of release are expected. Finally, the consistency in release parameters and throwing distance is analyzed, whereby the inter-individual variance in performance is expected to be larger in shot put throwers with II compared to non-II-throwers for all parameters assessed.

Materials and methods

Participants

A sample of 20 shot-put throwers with mild II (11 men, $M_{\text{age}} = 28.8 \pm 5.7$ years, $M_{\text{IQ}} = 60.0 \pm 6.5$ and 9 women, $M_{\text{age}} = 27.1 \pm 8.1$ years, $M_{\text{IQ}} = 60.3 \pm 8.5$) was included in this study, representing all participants of the shot put competition during the 2014 Open European Championships Athletics in Bergen op Zoom, The Netherlands. All II-throwers met the criteria for diagnosis of an Intellectual Disability (ID), according to the American Association on Intellectual Disabilities, (17) which is characterized by significant deficits in adaptive behaviors and intellectual functioning ($\text{IQ} \leq 75$), manifested prior to age 18. The participants represented 10 European Countries. A written informed consent was obtained from all participants or their legal guardians, prior to participation in the study. The Medical Ethics Committee of the KU Leuven approved the study. The control group consisted of 26 Belgian shot put throwers without II (12 men, $M_{\text{age}} = 25.5 \pm 5.5$ years and 14 women, $M_{\text{age}} = 24.5 \pm 5.6$ years). This sample represented all participants of the shot-put competitions during the 2015 Flemish and 2015 Belgian Championships Athletics in Ghent, Belgium; 14 out of 26 athletes participated in both Championships. Detailed information regarding training history (years of experience and training volume per week) is provided in Table 1. IQ data were not

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available for the control sample; however, assuming a normal distribution in the population, $IQ > 75$ was expected.

Data collection

Data was collected during competition, without interference or manipulation of the competition circumstances. The shot put weight was 7.26kg for men and 4kg for women (official competition weight). One stationary camera (Go Pro Hero 3⁺, Silver edition, operating at 100Hz, 720px120fps narrow field of view), was used to capture the motion of the throwers. The camera was placed at the right hand side of the participant, perpendicular to the direction of release, so that the point of release was in the middle of the camera view. Before the start of the competition, calibration was done, placing a calibration stick (with calibration marks every 10cm) in vertical and horizontal plane in the middle of the camera view to ensure a correct measurement.

Data analysis

In all competitions every competitor had three attempts and the top eight throwers received three additional attempts. The outcome variables for competition results were retrieved from the official competition results. Four variables were reported: (a) the average distance thrown per competitor, (b) the maximum distance thrown per competitor, (c) the distance of the winning throw of the gold medalist, and (d) the ratio white flag throws/attempts per thrower. (18) . All video recordings were manually digitized and analyzed using Dartfish Connect version 7.0 and Kinovea Version 0.8.15 motion analysis software by one trained researcher. Another, experienced researcher re-analysed 10% of randomly selected video recordings to ensure the accuracy of the obtained measures. The results of reliability analysis was $>.90$ ($p \leq .001$). Both video motion analysis systems,

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operating at 100Hz were used to obtain the outcome variables for the release parameters as described below. We defined the moment of release as the last frame in which the hand of the thrower was in contact with the shot. For each trial, the video-recordings were digitized starting five fields before the release and ending five fields after the shot was released. Coordinates of the center of the shot were obtained from every field. Three variables were reported: (a) the angle of release ($^{\circ}$), defined as the angle at which the shot is released relative to the horizontal axis, (b) the release velocity (m/s), defined as the velocity of the shot at the moment of release from the hand, and (c) the release height (m), defined as the height of the center of the shot above the surface of the ring at the moment of release. Coefficients of Variance (CoV) were calculated by means of the formula $(SD/M)*100$, as a measure of inter-individual variability for the angle of release, velocity of release, height of release and average distance thrown. Statistical analyses were performed using IBM SPSS Statistics software (version 22). The level of significance was set at $p<.05$. Independent t-tests were used to compare age, training volume, competition result, and release parameters between throwers with and without II. Cohen d effect sizes were calculated (<http://www.uccs.edu/~lbecker/>), with ≥ 0.2 considered a small effect, ≥ 0.5 representing a medium effect and ≥ 0.8 representing a large effect. (19) Pearson's correlation coefficients were calculated to determine the relationship between competition result and release parameters.

Results

Appropriate data screening techniques were used to confirm the assumptions underlying the statistical analyses used. An overview of participants' characteristics and the outcome of the shot put competition is reported in Table 1. No significant differences were observed for age and training volume. Small ($\geq .2$) to medium ($\geq .5$) effect sizes were reported

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for the participant's characteristics. The competition result (best performance and average performance) was significantly better for II-throwers compared to non-II-throwers, with large effect sizes ($\geq .8$).

To put the performance during competition in perspective, the result (in meters) of the winning throws (gold medal winners) can be expressed as a percentage of the world-records in their respective categories. During the II-European Championships the gold medal throw in the male II-competition (14.8m) was 90% of the male II-world-record-throw (16.29m), whereas the gold-medal-throw in the non-II national competition (17.8m) was only 76% of the world-record performance (23.12m). The difference is even more pronounced in the female competition, where the gold medal throw in the II-European Championship is 93% of the female II-world record performance, whereas the gold medal throw in the non-II-competition is 69% of the world record performance (See Figure 1).

The comparison of shot put release parameters between throwers with and without II is shown in Table 2. The release height was not significantly different between II and non-II-throwers. The release velocity was significantly larger for non-II throwers compared to II-throwers. The angle of release was significantly different for the females with II-females throwing with smaller angles compared to non-II-females. Large effect sizes ($\geq .8$) were observed for the angle and velocity of release parameters, in males and females.

A Pearson's correlation coefficient was used to determine the relationship between release parameters and shot put performance in competition. The highest positive correlation was found between the competition result and the release velocity ($r = .79$, $p < .01$). Moderate positive correlations were found between competition result and release angle ($r = .38$, $p < .01$) and between competition result and height of release ($r = .42$, $p < .01$).

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The CoV's were calculated for the release parameters and for the distance thrown, as a parameter of inter-individual variability. The results of the CoV comparisons are displayed in Figure 2. The CoV was significantly different for release velocity, with II-throwers performing more consistent compared to non-II-throwers, and the CoV was also significantly different for the distance thrown per attempt, with II-throwers performing less consistently compared to the non-II-throwers. No differences in consistency were found for release height and angle of release.

Discussion

This study compared the shot put performance, release parameters and consistency in shot put performance and release parameters between throwers with and without II. The results of this study revealed that national level throwers without II were able to throw further in competition than European level II-throwers. This finding provided an initial indication that the level of performance is not equal, although the total training volume was comparable between both samples. . Crucial to add here is the general remark that the level of professionalism in elite II-sport compared to regular elite sport is not equal, despite comparable training volumes. Differences exist in training quality, access to top-coaches, prize money and sponsorship among other factors (32).

In literature, the release velocity was unquestionably reported as the most important factor contributing to shot put performance. (7, 9, 20) As expected, in the current study, release velocity was most strongly related with the competition result. The average measured release velocities of the non-II-throwers (national level athletes) in the present study were at

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the lower end of the range of optimal velocities reported in the literature (12.5 – 14.5 m/s); (10) whereas, the measured velocities for II-throwers were situated well below this range (9.4m/s female, 10.9 m/s male). The lower release velocities of II-throwers confirmed the findings of Willwacher *et al.* (16), i.e., release velocity of 9.7m/s for II-throwers compared to 11.4m/s-13m/s for non-II throwers.

With respect to the angle of release, differences between II- and non-II-throwers were also expected; however, the observed differences were only significant for the female sample, with female II-throwers releasing the shot in a 30.6° angle, compared to a 36° angle in female non-II throwers. The theoretically optimal angle is approximately 40°-41°; however, most world-class shot-putters use lower release angles, ranging from 26° to 45°, with an average reported value of approximately 37° (e.g., (7, 12-14)) The average angle of release of six male II-throwers in the study by Willwacher *et al.* (16) was 36.6°; which, did not deviate substantially from the comparison samples of world class shot-put throwers they mentioned in their study (34.5°-37.4°); however, the angle of release was smaller than a sample of intermediate level throwers (41.0°). It should be noted that no statistical testing was performed and no comparison group was effectively assessed. In addition, Willwacher and his colleagues (16) only investigated 6 male throwers with II, and had no female participants. Hence, it is not possible to fully compare findings.

As hypothesized (and also confirmed in Willwacher *et al.* (16)), no significant differences were found for release height between throwers with and without II in the present study. It is known that release height has a greater relationship to anthropometric characteristics of the athletes, rather than their level of skill. (6)

In shot put, no highly strategic decisions need to be made, the key KPI's are explosive muscle strength and technique. More specifically, the ability to perform precisely timed movements in a confined space is crucial. (10) Therefore, it was expected that impaired

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cognition would constrain the ability of elite throwers with II to perform optimally and consistently. Consistency is a crucial aspect within sport performance, particularly in sequential motor skills. (21) Previous research exploring the mechanisms of learning a sequential motor skill outlines that two basic components must be considered; a) explicit identification of ordering movement units, b) implicit acquisition of individual movement units. (22) There is ample evidence outlining that the ability to perform both these components is related with cognitive function, and significantly affected in individuals with II. (23-26) It has been demonstrated that sensorimotor integration is limited and less consistent in individuals with II. (26, 27) Westendorp, Houwen, Hartman, and Visscher (26) demonstrated that children with II had motor problems related to timing and coordination of movement sequences. They were able to perform simple movements; however, when more parts of the body were involved simultaneously, children with borderline and mild II had greater problems than typically developing children with coordinating movements that involved both sides of their body or both upper and lower extremities. Extrapolating this knowledge to the population of athletes with II it can be assumed that they find it difficult to learn individual skills, and then order them fluently in an optimal pattern.

The shot put technique is a complex skill, because of the serial coupling of movement units in a very well timed fashion. Due to this complexity, II-throwers were expected to be less mature in the execution of this complex skill and therefore also to demonstrate higher inconsistency compared to non-II throwers. To verify this hypothesis, CoV's were calculated for all parameters. Looking at the outcome of the skill (i.e., the distance thrown in competition) the hypothesis was confirmed; however, analysing the release parameters, no differences in consistency were observed for the height of release and angle of release. Surprisingly, the inter-individual variability in release velocity appeared to be larger for non-II-throwers, indicating a less consistent release velocity compared to II-throwers, which was

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opposite to what was expected. The final release velocity of the shot is the culmination of all the movement units across the circle up to the release and poorly executed movement units across the circle negatively affect the final release velocity. (5, 28) It is not clear why the release velocity was less consistent for the non-II-throwers. One element that may contribute to explain this finding is the different shot put techniques applied in competition. In total, three techniques can be applied: (12) stable stance, gliding or rotational style. The stable stance technique was not used by any of the participants; however, both the gliding and rotational styles were performed. The rotational style or spin; whereby, the thrower initiates the movement from a low starting position to then straighten during the projection phase whilst rotating, thus diminishing the loss of speed, (12) was performed by only one II-thrower (female); however, by five throwers without II (4 male, 1 female). The other participants performed the gliding style (without rotation), which is most often used by throwers who are very big and strong but perhaps have a lower ability to move their limbs and body rapidly in a complex movement pattern. Coh, Stuhlec, and Supej (29) argued that inter-individual variance is larger in the rotational style compared to gliding style due to larger deviations in stability and balance during the rotational phase. Converting a rotational movement into a linear movement can create inconsistency in the coupling between the drive and the release. As five non-II throwers applied the rotation style, this can be a partial explanation for the larger throw-to-throw variation in release velocity displayed by the non-II-throwers. Not only for the 'rotators', but also for the 'gliders' without II, it is likely that the coupling between drive and release contributes to the larger inconsistencies observed for the release velocity. In general, expert shot put coaches reported that the coupling is more fluent in expert throwers compared to novices. Novices, and more specifically young children, often experience difficulties in the early learning stages to effectively convert the velocity of the shot put during the drive into a high velocity at release, resulting in an immature shot put technique with no efficient coupling

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between the two phases. As a result, their release velocity is rather independent from the velocity during the drive. A less mature skill is less difficult to perform, and opposite to what we expected, the reduced complexity might lead to more consistency, specifically in release velocity, as was observed in this investigation for throwers with intellectual impairment. II-throwers might lack the ability to adopt small modifications in technique, and hence integrate less appropriate strategies to throw further; whereas non-II-throwers take the advantage of using repeated efforts to optimize technique. Finally, we considered the ratio of white flag throws/attempts per thrower to be a factor contributing to the unexpected differences in velocity consistency; however, the ratio was equal for throwers with II (78.33%) and without II (77.83%).

No strength measures were performed in the present study, although it is well known that individuals with II have significantly lower muscular strength compared to individuals without II. (30) It is not clear whether their reduced strength is directly related to their impairment, or a result of lower physical activity levels. Guidetti, Franciosi, Gallotta, Emerenziani, and Baldari (31) assessed the trainability of strength in track and field athletes, and basketball players with II. After a general force training program in combination with sport specific training, the muscular strength and muscular endurance of the forearm were significantly improved, as well as the upper and lower body strength. Van Biesen, Mactavish, Pattyn, and Vanlandewijck (32) demonstrated that table tennis technical proficiency was trainable in elite table tennis players with mild II; however, the II-athletes in their study were not able to reach the same level of proficiency than equally well trained players without II. Moreover, the table tennis players in that study were able to master the basic technical skills, whereas the differences in performance between II and non-II players were larger for the more advanced skills. These observations indicate that the ability of individuals with II to master a specific skill depends not only on the type and severity of the impairment, but also

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on the complexity of the skill to be mastered. It is important for coaches working with II-throwers to interpret this into their training programs. More in-depth knowledge about the shot put performance of their athletes is useful in order to improve the quality of training and enhance their chances on success. Coaches need to understand their athlete's individual performance profile to optimize shot put performance. Apart from these applications towards training and coaching of athletes with II, the results of the present study also have implications towards the actual eligibility process of athletes with II in the Paralympic Games. Currently, shot put is one of the three athletics events practiced by II-athletes at the Paralympic Games. To decide whether or not an athlete is eligible, classifiers decide, based on assessment and observation, whether or not the impairment of the athlete impacts on the key determinants of performance. Evidence-based systems for classifying the impact of II on sports may benefit from focusing on those areas of sports performance in which intellectual capacity plays a significant role (36), such as the tactical requirements and/or the technical requirements of performing the key activities, as these aspects are most likely influenced by the II. The results of the present study contribute to inform classifiers on which key determinants of performance they need to focus on during observational assessment before and during competition (i.e., efficient coupling of movement units, consistency, and release velocity).

Limitations

It is important and useful, with respect to further investigations, to address the drawbacks of the present study and its consequences for the results and their implications. Firstly, the number of participants was relatively small, primarily for the comparison of performance, where male and female subsamples were analyzed separately because of the different shot weight used in competition. Secondly, the data was collected at different

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occasions. The INAS European Championship was an outdoor competition during the outdoor season (June); whereas, the Flemish and the Belgian Championships were indoor tournaments, during the indoor pre-season (January, February), in which some athletes are fully in preparation for the outdoor competitive season. The intra-seasonal variations (33) may have affected the performance and/or consistency in performance of the participants. Finally, it is important to keep in mind that no data were available regarding the IQ scores of the non-II-throwers. Their IQ's are expected to fall within the normal ranges for the general population (i.e., $IQ > 75$); however, we need to be aware this being only an assumption.

Conclusion

Optimal performance in athletic throwing events is determined by various factors. The aim of this study was to explore if impaired cognition could be related to throwing performance, specifically in shot put. This study was one of the first to investigate key performance indicators and consistency of release parameters and distance thrown in shot put in a population of throwers with and without intellectual impairment. The overall competition result was significantly better in national level non-II-throwers than in European level II-throwers, although both samples had comparable training volumes. This was primarily related to the higher release velocity of non-II-throwers. Surprisingly, the non-II-throwers released the shot with higher velocities; however, also with less consistency than the II-throwers. In opposition, the inter-individual variance in throw-to-throw distance was larger in the II-throwers. More research is required to fully understand the importance of consistent versus inconsistent performance. Not only consistency over a season might be important, but also the ability to modulate performance across throws within a single competitive event. Overall, the

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findings of this study can be useful for coaches working with II-throwers, although further investigation is required into the learning strategies of II-throwers and their ability to master complex motor skills, despite having a cognitive impairment.

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Figure and Table Captions

Table 1: Participants' characteristics and competition result descriptive statistics.

Figure 1: Comparison of the gold medal winner's best performance during competition with the world record in the respective category.

Table 2: Comparison of shot put release parameters between shot put throwers with and without intellectual impairment.

Figure 2: Comparison of consistency in the release parameters and distance thrown between shot put throwers with and without intellectual impairments.