Section: Original Investigation

Article Title: The Impact of an Assistive Pole, Seat Configuration and Strength in Paralympic Seated Throwing

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The impact of an assistive pole, seat configuration and strength in Paralympic seated throwing

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Abstract

Purpose: This study quantified the influence of (i) the assistive pole, (ii) seat configuration, and (iii) upper-body and trunk strength, on seated throwing performance in athletes with a spinal cord injury. **Methods:** Ten Paralympic athletes competing in wheelchair rugby, wheelchair basketball or athletics (seated throws) participated in two randomised sessions; seated throwing and strength tests. Participants threw a club from a custom-built throwing chair, with and without a pole. 3D kinematic data were collected (150 Hz) for both conditions using standardised and self-selected seat configurations. Dominant and non-dominant grip strength was measured using a dynamometer and upper-body and trunk strength was measured using isometric contractions against a load cell. **Results:** Seated throwing with an assistive pole resulted in significantly higher hand speed at release compared to throwing without an assistive pole (pole=6.0±1.5 m/s and no-pole=5.3±1.5 m/s; p=0.02). There was no significant difference in hand speed at release between standardised and self-selected seating configurations during seated throwing with or without an assistive pole. Grip strength (r=0.59-0.77), push/pull synergy (r=0.81-0.84) and trunk flexion (r=0.50-0.58) strength measures showed large and significant correlations with hand speed at release during seated throwing with and without an assistive pole. **Conclusions:** This study has demonstrated the importance of the pole for spinal cord injured athletes in seated throwing, and has defined the relationship between strength and seated throwing performance allowing us to better understand the activity of seated throws and to provide measures for assessing strength that may be valid for evidence-based classification.

Key Words: Biomechanics, classification, spinal cord injury, track and field, physical impairment.

Introduction

The Paralympic games are the largest sporting event for athletes with a disability. The primary aim of classification in Paralympic sport is to minimise the impact of impairment on the outcome of competition.[1] If this aim is achieved, it ensures that an athlete succeeds in their chosen sport based on talent, training commitment, proficient technique and fitness, rather than an inequality in levels of impairment.[2] Currently the methods that are used to assign class in Paralympic sport only partially satisfy the criteria for evidence-based classification.[1] Under mandate from the International Paralympic Committee, sports are required to develop methods that will allow evidence-based classification. Because quantification of the strength of association between measures of impairment and performance is fundamental to the development of evidence-based classification, precise, ratio-scaled and valid measures of impairment and performance are required in classification research.

Throwing events in Paralympic athletics are commonly performed using a secured throwing technique as described in Rules 35 and 36 of the IPC Athletics Rules and Regulations.[3] Athletes with a physical impairment are divided into 11 classes that include athletes with hypertonia, ataxia or athetosis as well as athletes with loss of muscle strength, limb deficiency or loss of range of movement. Athletes with spinal cord injury compete in classes F51 to F54 with lower numbers indicating higher impairment severity.[4,5] Athletes in these classes compete in javelin, discus and shot-put events similar to able-bodied athletes, but from a custom-built throwing frame (seat) rather than with a run-up or glide resulting in significantly different throwing techniques.[6-8] A unique event to Paralympic athletics is seated club throwing, which allows for athletes with the most severe impairments to participate. In this event, athletes with a disability can use a diverse range of throwing techniques, including generic overhead and underarm throwing, as well as throwing from a backwards facing position (Figure 1).

The kinematic characteristics for seated throws events in athletics have been limited to javelin, discus and shot-put that have found performance-related kinematics to relate to classification.[6,9-11] These studies used two video cameras to record seated throws, and possible errors may have resulted from manual digitising, despite attempts to use quality control processes. Nevertheless, these studies have provided important insights into the performance-related kinematics of seated throws events, and have shown that high angular velocities of the trunk, shoulder girdle and upper arm during the delivery phase to be important determinants of classification and measured throwing distance.[9-11] For athletes with a spinal cord injury, impairments of strength that influence their ability to produce and effectively transfer momentum from and to the trunk, shoulder girdle and distal limbs are most relevant to seated throwing performance, and should be accounted for during the classification process.

Muscle strength in athletes with a spinal cord injury varies for any given lesion level, and so measures for assessing how much trunk and arm strength impairments affect throwing performance are essential for developing an evidence-based classification system. Current classification methods to assess strength impairment involve manual muscle testing (MMT).[12] Such tests have questionable reliability, and the ordinal nature of MMT does not allow the use of inferential statistics to determine the relationship between impairment and performance.[1,12,13] Therefore measures of eligible impairments that are reliable, ratio-scaled, and valid for the purposes of classification (i.e., they should explain significant variance in athletic performance) need to be developed.

The assessment of seated throwing performance in classification research requires athletes to perform a standardised test, which should permit maximal or close to maximal performance and be within the technical rules of the sport.[1,14] Seated throws events include several different throwing implements and techniques, and seated club throwing consisted of only four out of a total of 52 throwing events at the recent 2016 Rio Paralympic games.

However, the club allows athletes with limited wrist and hand function to compete, and offers a generic overhead seated throws activity that can be standardised for a wide range of impairment severities. The technical rules also allow athletes to use an assistive pole, and athletes use this feature while others do not, depending on their nature of impairment and preferred throwing technique. Research has shown a link between the use of an assistive pole and Paralympic seated throwing performance[7,15]; and research in able-bodied participants suggests the assistive pole allows for higher shoulder internal rotation angular velocities during the delivery phase of generic overhead seated throwing.[16] Additionally, athletes are permitted to self-select the seat position relative to the throwing direction, as well as the height of the back rest. The factors influencing an athlete’s selection of the throwing frame configuration are multifaceted, and include their nature of impairment, and their desire to improve performance and comfort.[7,17] Research has established the seated throwing frame configurations preferred by non-disabled people, allowing for the development of a standardised activity test to evaluate the impact of impairment on seated throwing performance.[17] The purposes of this study were to quantify the influence of (i) the assistive pole, (ii) seat configuration, and (iii) upper-body and trunk strength, on seated throwing performance in athletes with a spinal cord injury.

Methods

Participants

Eight male and two female, spinal cord injured athletes participated in this study (age 32±10 yrs; sitting height 90±6 cm; body mass 73.8±9.8 kg; range of lesions were; L1, L1-L2, T4, T6, C5-C6 and C6). Participants were recruited if they had an impairment that was eligible for participation in Paralympic seated throwing. All participants had represented their state or country in either wheelchair rugby, wheelchair basketball or athletics (seated throws) and were currently training and competing for their Paralympic sport. Each participant signed an informed consent form prior to the study and institutional review board approval was granted in the spirit of the Helsinki Declaration (A/09/191).

Design

This study employed a crossover design that involved collection and analysis of two components; seated throwing kinematic performance data and seated strength data to assess impairment. Athletes with a spinal cord injury participated in both the seated throwing and strength session, in random order. A 3D kinematic analysis was used to quantify the influence of seat configuration and an assistive pole on the performance-related kinematics of seated throwing. The influence of upper body and trunk strength on seated throwing performance was determined using isometric strength tests assessed using a custom-built device.

Methodology

Kinematic analysis of seated throwing. Each participant performed a self-selected warm up. Participants were allowed an unlimited number of submaximal and maximal throws with the throwing club. This was carried out to familiarise the participant with the throwing club that would be used for the study and the throwing action required. To allow for a standardised activity limitation test, all participants used an international throwing club that allowed athletes with a high spinal cord injury (limited hand and wrist function) the ability to ‘grip’ the throwing implement. Athletes were permitted to have their cushion on the throwing chair for the duration of the study. The lower body was secured to the throwing chair using a 25mm wide strap across the pelvis and another across the mid-thigh. The feet were strapped to the adjustable footrest so that hips, knees and ankles were positioned at 90°. The specifics of the throwing chair and its design have been detailed elsewhere.[17]

There were two conditions in the seated throwing component of the study; (i) no-pole condition and (ii) pole condition. Participants were required to throw three, maximal seated overhand throws from both a standardised and self-selected seating configuration during the no-pole and pole conditions. Three throws were captured from each of the experimental conditions and the best throw, determined by the highest hand speed at release, was used for statistical analysis.

In the no-pole condition, participants threw from two different seating configurations.

(i) The starting seat configuration (derived from pilot testing conducted on able-bodied participants[17]) consisted of a seat angle of 30° and a backrest height of 18% of the athletes sitting height.

(ii) The second seat configuration was self-selected. Seat angle, backrest height and the use of the backrest strap could be altered for this position. Unlimited practice throws were permitted prior to the three recorded throws, in order for the participant to find their preferred seat configuration.

In the pole condition, participants threw from two different seating configurations.

(i) The first seat configuration (derived from pilot testing conducted on able-bodied participants[17]) consisted of a seat angle of 20°, a backrest height of 15% of the athletes sitting height, an elbow angle of 84°, assuming a fully extended elbow is 180°, and a pelvic angle relative to the pole of 112°.

(ii) The second seat configuration was self-selected in which any of the variables could be altered.

Kinematic data were collected using the Qualisys Motion Capture System (V2.2) (Gottenburg, Sweden) using a 32 retro-reflective marker set.[17] Six infrared cameras operating at 150 Hz tracked the participant’s seated throws. This measurement system has been shown to have a root-mean-square error of 0.8 mm for the measurement of distance between two fixed points.[18] Qualisys software used standard Direct Linear Transfer methods to create 3D coordinates which was then used to construct a 3D model of the body.[19] Kinematic parameters were calculated using Visual 3D (V4.75.30) (C-Motion Inc. 15821-A Crabbs Branch Way

Rockville, USA). Kinematic data were collected for the following phases within the throw; (i) start of the forward movement, (ii) cocking of the throwing arm, (iii) arm acceleration phase, and (iv) club release.[20,21] The kinematic variables selected for this study (Table 1) were based on previous ambulant and non-ambulant overhead throwing research.[10,22,23]

Isometric strength testing. Each participant performed five upper body strength tests with three maximal effort trials for each test. All contractions lasted between four and 10 s and were performed on each minute giving participants at least 50 s rest between consecutive trials.[12] Each participant was given the same set of instructions prior to and during the contractions. The tests consisted of a (i and ii) throwing and non-throwing hand grip strength test, (iii) throwing arm push test, (iv) push/pull synergy test (v) and trunk flexion test.

Throwing and non-throwing hand grip test. Participants held a grip strength dynamometer (Smedlay's Dynamometer, Fabrication Enterprises, White Plains, USA) with their arm positioned by the side of the body and elbow flexed at 90°. Grip size was adjusted for comfort accordingly. Three maximal contractions were performed with both the left and right hand with 10 s rest between each trial.

Throwing arm push test. Participant was supported with a backrest reaching C8 and hips and knees were secured with straps at 90°. In a seated position, the participants arm was positioned with 90° of shoulder flexion, 45° of horizontal shoulder flexion and 120° of elbow extension (Figure 2A). The arm remained parallel to the floor throughout each contraction. Contractions were performed against an S-type load cell rated to 394 kg (Scale Components, Slacks Creek, Queensland).

Push/pull synergy test. Participants were in the same position as the Dominant Arm Push test but were not supported with a backrest. The dominant hand was placed on the load cell and non-dominant hand was gripping the pole (Figure 2B). The pole was used as an aid to increase the force of the dominant hand.

Trunk flexion test. During this test the load cell was placed on a box on the floor and the participant was strapped to the seat. Each participant had both hands on the load cell and was positioned into 45° of trunk flexion and 120° of elbow extension. A rest measure was taken as the participant slowly extended their arms. Participants were required to hold the position and push down on the load cell using their trunk muscles, not their arms. Specific instructions were given to each athlete to ensure they used only trunk muscles for this test.

Statistical Analysis

Differences in kinematic variables between no pole and pole conditions, as well as standardised and self-selected throwing configurations were determined using a within-subject repeated measures analysis of variance (ANOVA). Significance was set at $p \leq 0.05$ and the source of significant effects was determined using a Bonferroni's post hoc test. Non-clinical magnitude based inferences were also calculated and reported as trivial (<0.2), small (0.2-0.6), moderate (0.6-1.2) large (1.2-2.0) and very large (>2.0) using previously standardised criteria.[24,25] When the 90% confidence interval (CI) crossed the threshold for both a substantially positive (0.2) and negative (-0.2) value, the effect was reported as unclear.[25] Pearson's correlation coefficients were calculated to determine the relationship between strength measures and hand velocity at release for both the pole and pole conditions. Correlations were identified as unclear (<0.1), small (0.1-0.3), moderate (0.3-0.5), large (0.5-0.7), very large (0.7-0.9) and almost perfect (>0.9).[24]

Results

The repeated measures ANOVA showed no significant interactions between the pole and seat configuration conditions for any of the kinematic variables. There was a significant main effect for the pole condition, showing overall differences between the pole and no-pole conditions for elbow flexion at the start of the throw (pole=94±39 deg and no-pole=98±41 deg; p=0.04), maximum shoulder external rotation velocity during the cocking phase (pole=264±238 deg/s and no-pole=175±133 deg/s; p=0.04) and hand speed at release (pole=6.0±1.5 m/s and no-pole=5.3±1.5 m/s; p=0.02). When throwing from the standardised seat configurations, participants showed small to moderate increases in maximum shoulder external rotation velocity during the cocking phase and hand speed at release during the pole condition compared to the no-pole condition (Table 1).

The mean self-selected seat configurations for the no-pole condition were a seat angle of 28±9 deg and backrest height of 25±11 cm. For the pole condition, the mean self-selected seat configurations were a seat angle of 19±3 deg, backrest height of 25±11 cm, elbow angle of 113±15 deg and pelvis angle of 112±4 deg. There was no significant main effect for seat configuration on any of the kinematic variables of seated throwing. Participants showed a small increase in hand speed when using their self-selected seat configuration during the no-pole condition (standardised=5.1±1.5 m/s and self-selected=5.4±1.5 m/s; ES=0.21±0.38), and there were also small differences in ipsilateral trunk rotation during the cocking phase (standardised=-43±15 deg and self-selected=-49±15 deg; ES=0.38±0.57) and trunk flexion at release (standardised=-40±15 deg and self-selected=-30±18 deg; ES=0.58±0.73). There was no clear difference in hand speed between standardised and self-selected seat configurations during the pole condition.

Measures of strength showed trivial to very large correlations with hand speed at release during seated throwing with and without an assistive pole (Table 2). Grip strength and push/pull synergy showed the strongest correlations with hand speed at release, whilst throwing arm push strength and trunk flexion strength showed small to large, non-significant correlations.

Discussion

Several outcomes of this study provide important advances towards evidence-based classification methods. Firstly, compared to the no-pole condition, the assistive pole was associated with increased hand speed at release in our sample of athletes with spinal cord injury.

Secondly, no significant effect of seat configuration was found in the pole or the no-pole conditions. Thirdly, three of the isometric strength tests showed strong correlations with hand speed at release with and without an assistive pole indicating their potential use in assessing strength impairment in Paralympic seated throwers. This study provides a more comprehensive understanding of factors that affect seated throwing performance, an important pre-requisite to the development of measures of impairment and throwing performance in classification research.

This study found athletes with a spinal cord injury improved seated throwing performance using an assistive pole. In Paralympic seated throwing events, the assistive pole is used by some athletes for additional support and balance during their throws. Results from previous studies indicated that an assistive pole has no significant effect on hand speed at release in non-disabled people.[16,17] Comparatively, our study indicates that the assistive pole allows athletes with a spinal cord injury to compensate for loss of trunk and upper body strength, and to increase hand speed at release compared to throwing without an assistive pole. The main kinematic differences when throwing with compared to without an assistive pole in non-disabled people, is an increase in maximum external and internal rotation angular velocities around the shoulder during the arm cocking and acceleration phases of the throw.[16] These kinematic variables were also shown to be key determinants of higher hand speeds at release when throwing with a pole.[16] For Para-athletes with spinal cord injury, it is possible that the assistive pole allows for greater angular momentum to be produced and transferred by the more distal limb segments, such as the shoulder, rather than by the proximal musculature of the trunk. This would explain Para-athletes with spinal cord injury being able to produce higher hand speeds at release when throwing with a pole, as impaired trunk strength would have less impact on the end-point velocity, compared to throwing without a pole.

Despite the increase in hand speed in the pole condition, there were no significant differences in seated throwing kinematics of the trunk or throwing arm between the no-pole and pole conditions, except for an increase in maximum shoulder external rotation angular velocity during the cocking phase of the throw. Greater maximum shoulder external rotation angular velocity has been correlated with higher hand speeds at release during seated throwing in non-disabled people and may explain, at least in part, the higher hand speeds produced by this study's participants when throwing with a pole.[16] The lack of significant differences in kinematic variables during the arm acceleration phase between pole conditions, may be explained by the heterogeneity of impairments within the relatively small sample. In order to maximise hand speed at release, it is likely that individual athletes in our sample had personal adaptations to the constraints of the throwing activities which increased the variability of the kinematic outcomes.

No significant effects of seat configuration on hand speed were found in the pole or no-pole conditions. However, seat configuration was associated with a small difference in trunk flexion and hand speed at release in the no pole condition and a small difference in maximum shoulder external rotation during the cocking phase in the pole condition. These kinematic differences represent the unique adaptations to altered seat positioning relative to the throwing direction. Together, these results suggest that the impact of strength impairments on seated throwing performance can be evaluated in classification research with athletes in a standardised seat position.

An important finding of this study was the identification of isometric strength tests that significantly relate to seated throwing performance in athletes who have a spinal cord injury. Isometric grip strength in the throwing arm and the push/pull synergy tests had the strongest relationship with seated throwing performance in both the pole and no-pole conditions (Table 2). While further studies are required in a larger sample of athletes with spinal cord injury to confirm these findings, these tests might provide objective, ratio-scaled measures to assess strength impairment for evidence-based classification in Paralympic seated throwing events.

There are a number of limitations of this study that warrant discussion. First, seated throwing performance was assessed solely on hand speed at release, and the trajectory of the throwing implement at release has also been shown to be an important determinant of throwing distance.[6] Unfortunately, the centre of mass of the throwing club was not tracked during the 3D kinematic analysis of the current study. Further research is merited to determine if throwing trajectory is influenced by strength impairment, and whether it should be considered during the classification process. Another limitation is the small sample of athletes with a spinal cord injury that were included in this study, which included athletes from a range of different Para-sports. The factors that influence seated throwing performance of novices may not be the same as those that affect highly trained seated throwers. It is important to note, that the athletes in this study were all eligible to compete in Paralympic seated throws events, and therefore this study’s participant cohort was not dissimilar to those athletes who commonly undertake international classification for seated throws. Nevertheless, future longitudinal studies that include a larger, racially diverse sample of trained Paralympic seated throwers are required to establish the relationship between strength measures and seated throwing performance, and how these measures respond to sport-specific training regimes, so that they can be used to infer loss of strength during the classification process.

Practical Applications and Conclusions

The findings of this study provide important advancements towards the development of evidence-based classification systems for Paralympic seated throwing events. The impact of strength impairments on seated throwing performance should be evaluated in both pole and no-pole conditions in classification research. Because the pole influences seated throwing performance, the effect of strength impairment on seated throwing with and without an assistive pole is likely to differ. If this is confirmed in future research, then there are two possible implications regarding the classification system and technical rules for seated throwing activities. One possibility is that athletes who throw with and without a pole compete in separate competitions. The second possibility is that all seated throwers use the same equipment (i.e., all athletes throw without an assistive pole or with an assistive pole). In regard to seat position, the impact of strength impairment on seated throwing performance can be evaluated when athletes are placed in a standardised seat configuration. Finally, this study showed a number of isometric strength tests were strongly correlated with hand speed at release during seated throwing with and without an assistive pole, and may have utility to infer loss of strength during the classification process for seated throwing athletes who have strength impairments.

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Figure 1. Examples of Paralympic seated club throwing (A) with and (B) without the use of an assistive pole.

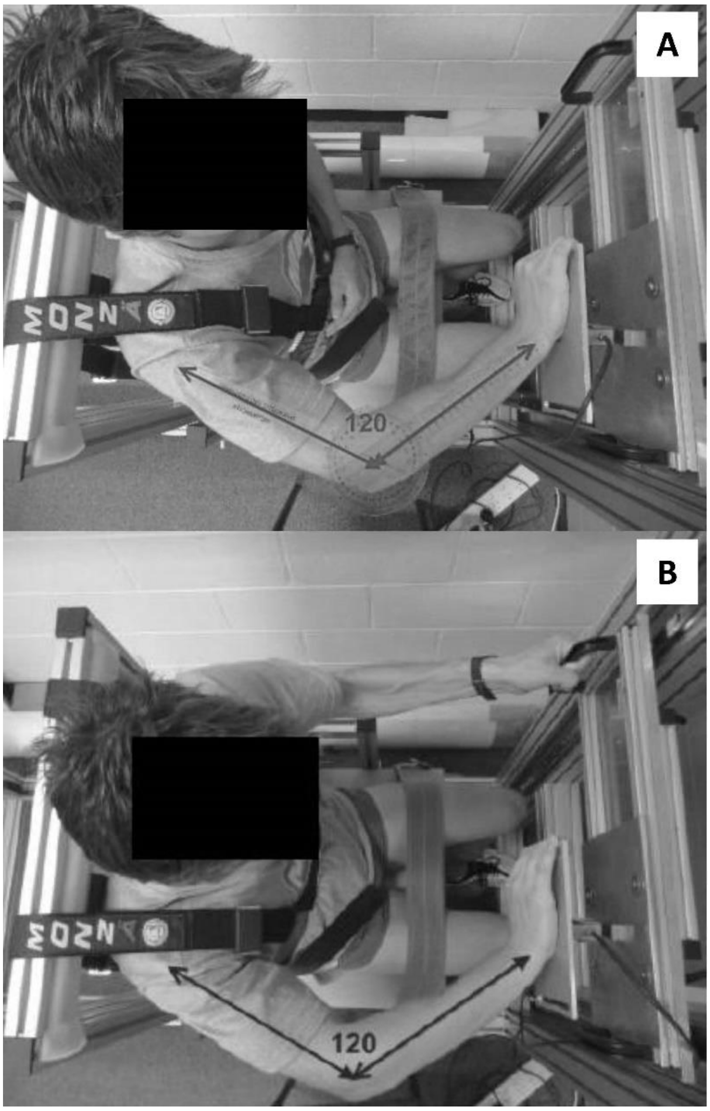

Figure 2. Participant positioning for the (A) throwing arm push test and (B) push/pull synergy test.

Table 1. Descriptive kinematic parameters, mean (95% CI), showing differences between pole and no-pole conditions during seated throwing using standardised and self-selected seat configurations.

	Standardised seat configuration				Self-selected seat configuration			
Kinematic variable	Pole (n=10)	No-pole (n=10)	ES ± 90% CI	QO	Pole (n=10)	No-pole (n=10)	ES ± 90% CI	QO
Start								
Elbow flexion (deg)	94 (66, 123)	96 (65, 127)	0.05 ± 0.80	Unclear	94 (65, 122)	101 (71, 130)	0.19 ± 0.79	Unclear
Cocking								
Maximum shoulder external rotation angular velocity (deg/s)	315 (104, 526)	149 (70, 228)	0.71 ± 0.77	Moderate	212 (95, 329)	201 (90, 311)	0.07 ± 0.80	Unclear
Trunk extension (deg)	8 (-7, 24)	-1 (-19, 17)	0.40 ± 0.78	Unclear	8 (-1, 17)	4 (-9, 16)	0.31 ± 0.79	Unclear
Maximum shoulder external rotation (deg)	-118 (-183, -95)	-106 (-130, -83)	0.36 ± 0.78	Unclear	-107 (-133, -80)	-100 (-120, -79)	0.21 ± 0.80	Unclear
Ipsilateral trunk rotation (deg)	-42 (-50, -34)	-43 (-54, -32)	0.07 ± 0.80	Unclear	-45 (-59, -32)	-49 (-60, -39)	0.22 ± 0.80	Unclear
Arm Acceleration								
Maximum shoulder internal rotation angular velocity (deg/s)	-173 (-308, -39)	-182 (-304, -60)	0.06 ± 0.94	Unclear	-194 (-337, -51)	-173 (-310, -36)	0.13 ± 0.91	Unclear
Maximum elbow extension velocity (deg/s)	-702 (-833, -571)	-688 (-806, -569)	0.09 ± 0.82	Unclear	-687 (-828, -545)	-711 (-876, -545)	0.12 ± 0.83	Unclear
Trunk angular velocity (deg/s)	212 (153, 271)	250 (161, 339)	0.41 ± 0.88	Unclear	258 (185, 330)	312 (261, 364)	0.62 ± 0.77	Moderate
Release								
Hand speed (m/s)	6.0 (4.9, 7.1)	5.1 (4.0, 6.1)	0.59 ± 0.76	Small	6.0 (5.0, 7.0)	5.4 (4.4, 6.5)	0.39 ± 0.78	Unclear
Trunk flexion (deg)	-38 (-48, -29)	-40 (-51, -29)	0.13 ± 0.83	Unclear	-39 (-50, -29)	-30 (-43, -16)	0.47 ± 0.83	Unclear
Elbow angle (deg)	44 (31, 56)	39 (26, 51)	0.30 ± 0.79	Unclear	44 (33, 55)	40 (27, 55)	0.21 ± 0.80	Unclear
Contra-lateral trunk rotation (deg)	16 (5, 27)	11 (-7, 29)	0.22 ± 0.80	Unclear	14 (5, 23)	12 (-4, 28)	0.13 ± 0.81	Unclear

*Significant difference ($p<0.05$) between seat configurations; ES = effect size; CI = confidence interval; QO = qualitative outcome.

Table 2. Mean strength scores (n=10) and Pearson's correlation coefficients between strength score and hand speed at release for no-pole and pole conditions during standardised seating configurations.

	Mean (95% CI)	No-pole (*r*)	pole (*r*)
Grip throwing (kg)	34.4 (17.8, 51.0)	0.64*, large	0.77*, very large
Grip non-throwing (kg)	31.4 (18.5, 44.3)	0.59, large	0.62*, large
Throwing arm push (N)	340.6 (231.8, 449.4)	0.01, unclear	0.31, moderate
Push/pull synergy (N)	221.7 (149.1, 294.4)	0.81**, very large	0.84**, very large
Trunk flexion (N)	72.7 (16.8, 128.5)	0.50, large	0.58, large

Correlations (*r*) are identified as unclear (<0.1), small (0.1-0.3), moderate (0.3-0.5), large (0.5-0.7), very large (0.7-0.9) and almost perfect (>0.9).

**Correlation is p<0.01.
*Correlation is p<0.05.