

Applied biomechanics for evidence-based training of Australian elite seated throwers

LAURENT FROSSARD^{1,2}, ALISON O’RIORDAN^{3,4}, SCOTT GOODMAN⁴

¹ School of Engineering Systems, Queensland University of Technology

² Institute for Health & Biomedical Innovation, Queensland University of Technology

³ School of Human Movement Studies, Queensland University of Technology

⁴ Athletics Australia, Australian Institute of Sport

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Abstract

Research in biomechanics is one method available to improve the understanding of the performance of elite seated throwers, which depends on the interaction between the design of the athletes’ throwing frame and their throwing technique. The main purpose of this paper is to provide an outlook on the two approaches currently underlying this research. The specific objectives are (A) to describe the procedure, outcomes and limitations of the conventional approach, based on fundamental research, (B) to present the innovations and dynamic research procedure of an integrated approach based on applied research, as implemented by a multi-disciplinary team working together since 2000, from Athletics Australia (AA), the Australian Institute of Sport (AIS) and Queensland University of Technology (QUT). This approach relies on the integration of biomechanics within an evidence-based training framework. Furthermore, an example of the work conducted during training, in experimental conditions and during real-event around the foot placement of F33/34 throwers will be provided.

Keywords: Biomechanics, athletics, field events, disability

1. Background

The performance of elite seated throwers, represented by the distance thrown, depends on the interaction between the design of the athletes’ throwing frame and their throwing technique.

Athletes are entitled to use their own throwing frame usually made of iron or steel (Figure 1). Most frames feature up to four legs, foot rests, and strapping systems to anchor the athlete to the seat and the frame to the ground. The typical seat area is composed of a flat surface with some form of cushioning that must be no higher than 75 cm from the ground. Athletes are also allowed to use a back-rest, and a pole at their discretion for balance purposes and/or to generate driving forces.

Traditionally, the design of the throwing frame is driven by the local resources available to the athletes, and by a trial and error approach relying on apparent functionality and sensations of comfort. Although this approach could appear relevant in principle, it is more questionable for some seated athletes with cerebral palsy and spinal cord injury as their sensations might be misleading.

*** Insert Figure 1 here ***

Athletes participating in seated throwing events, including shot-put, discus and javelin, are divided into classes to ensure fairness in the event. They are classified according to their gender and to their

functional level or “movement potential”, as well as their control and strength of various muscle groups. A summary of the seated thrower classification system and functional outcomes for Classes 52 – 58, is presented in Table 1. The throwing technique varies slightly from one class to another and from one athlete to another, as each individual tends to capitalise on her or his own functional capacities. In the case of the shot-put event, the typical technique involves a back thrust followed by a forward thrust of the upper body, completed by a full extension of the upper limb putting the shot.

*** Insert Table 1 here ***

Coaches and elite seated throwers are routinely carrying out visual analyses of their throwing technique, using commercial video recording systems (5, 6, 9-15). Such tools featuring replay and slowdown functions are relevant in giving useful qualitative feedback. However, such analyses provide limited quantitative biomechanical information for a deeper analysis of the throwing technique, or for a better understanding of the interaction between the throwing technique and the design of the throwing frame.

2. Purposes

Research in biomechanics is one method available to improve the understanding of this interaction. The main purpose of this paper is to provide an outlook on

the two approaches currently underlying this research, as presented in Figure 2. The specific objectives are:

- To describe the procedure, outcomes and limitations of the conventional approach, based on fundamental research.
- To present the innovations and dynamic research procedure of an innovative approach based on applied research, as implemented by a multi-disciplinary team working together since 2000, from Athletics Australia (AA), the Australian Institute of Sport (AIS) and Queensland University of Technology (QUT). This will include an example of the work conducted around the foot placement of F33/34 throwers.

3. Conventional approach

This approach is generally initiated by national coaches of national sports organisations requesting a biomechanical analysis of their elite seated throwers. The one-time data collection occurs in training conditions over a short period of time, usually at a training camp. Sport biomechanists usually provide a report several months later to the coaches and athletes, and it is the coaches’ responsibility to implement the recommendations. Some of the results may eventually be published in scientific journals (5, 6).

Essentially, such research focuses on the understanding of the throwing technique. For instance, kinematic studies are looking at parameters either underlying the sequence of actions taken by the athlete up until the release of the implement, and/or parameters determining the implement’s trajectory. These studies may also provide information that allows a link between disability, classification and performance to be established, since both sets of parameters are reflective of the functional outcomes of the athletes. For instance, Chow *et al* (2000) (5, 6) showed that “the height of the shot at release, the angular speed of the upper arm at release, the range of motion of the shoulder girdle during delivery, and the average angular speeds of the trunk, shoulder girdle and upper arm during the delivery, were all significantly correlated with both the classification and measured distance”.

The outcomes of this fundamental research are limited for coaches, athletes and sport scientists. Information collected in a training context may only be partially representative of the technique as performed by these athletes while competing in a world-class event. For instance, the elite shot-putters participating to Chow *et al*’s (2000) (5, 6) study performed on average $15\pm 9\%$ less than their personal best. As pointed out by Chow *et al*, 2000 (5, 6), “More quantitative data, especially those collected during major competitions, are needed for the development of a data base on performance characteristics”. In addition, continuous exchanges between coaches, athletes and sport scientists associated with recordings during the course of the developments of the athlete’s throwing technique and throwing frame will be more beneficial than a one off

analysis.

These limitations are partially due to a coaching culture where biomechanists are involved only occasionally, because of lack of proximity and/or common ground. A lack of resources often means that sports have to prioritise the areas they consider to be the most important for supporting their athletes and coaches. Subsequently, regular biomechanical analysis often falls low on the list of priorities.

4. Integrated approach

An innovative approach attempting to address these limitations has been developed by an Australian team working for Athletics Australia (AA), the Australian Institute of Sport (AIS) and the Queensland University of Technology (QUT), since 2000. This approach relies on the integration of biomechanics within an evidence-based training framework. This means that choices concerning throwing technique and/or frame design will be based on tangible biomechanical data. A unique combination of funding from sports organisations and research bodies provided sufficient resources to enable this leading applied research relying on three innovations to take place, as illustrated in Figure 2.

*** Insert Figure 2 here ***

4.1. Innovations

The innovations included:

1. The assembly of a multi-disciplinary team made up of coaches, athletes and biomechanists, but also engineers. This allows biomechanical issues to be addressed from a wider range of expertise.
2. Significant emphasis was placed on the design of the throwing frame. More than 20 significant modifications of the throwing frames for 12 elite Australian seated athletes have been implemented since the beginning of this partnership. Examples of modification are presented in Table 2 and include, seating arrangements, design and usage of the pole, points of contact of the athlete to the frame and overall positions of body segments during the throwing movement.
3. An increase in the testing environments including during training, in motion analysis laboratory and during real events, i.e. competition. The working group has recorded and partially analysed more than 6,400 attempts since 2000, including:
 - 3,120 attempts (6,352 video files) systematically recorded during all seven national and one overseas training camp of the Australian squad of seated throwers. Recording has also occurred during regular training sessions.
 - 180 attempts (1,800 files) recorded in 2004 during three testing sessions at the laboratory located at the AIS, focusing on the foot positions of two elite F34 athletes.
 - 1,366 attempts (2,940 files) were recorded during

- six national domestic events.
- 1,221 attempts (2,078 files) were recorded during the Sydney 2000 Paralympic Games and Lille 2002 IPC World Championship, corresponding to a cumulated number of 301 athletes, competing in 12 classes.

4.2. Dynamic research procedure

This evidence-based training has been implemented using a dynamic research procedure, involving an intricate data flow between three testing environments (training, laboratory and competition) and several key players (AA, IPC, QUT and AIS), as presented in Figure 3.

*** Insert Figure 3 here ***

The research during training was placed in the centre of this procedure in order to keep the overall research closely related to the real practical issues at ground level. More importantly, it is the most immediate and efficient way for coaches and athletes to access and benefit from biomechanical analyses.

A training session lasting about two hours, involving a biomechanist, will typically follow this procedure:

- The recording of between twenty and thirty attempts, focusing on a maximum of three topics for a given athlete.
- The visual analysis of video files will take place either immediately or later the same day, depending on weather and lighting conditions, schedule, level of relevance, etc. Immediate visual feedback is especially beneficial to athletes with cerebral palsy and spinal cord injury who can only rely partially on their proprioception. This helps them to build up a better representation of their movement. The analysis will be conducted by the coach, athlete and biomechanist, using replay, overlap and slowdown functions of the software. The features of the software help the coach and athlete to observe more accurately the throwing action that is often quick and complex. The debriefing allows the coach and biomechanist to select the relevant attempts to analyse, and the range of biomechanical parameters to be provided in more detail afterwards.
- The subsequent biomechanical analysis of the selected files will be conducted later on the same day. It consists of a simple kinematic analysis based on the 2D displacements of the distal and proximal extremities of each segment, pointed manually frame-by-frame. The accuracy of the tracking is better than one cm along the three axes. A customized Matlab software will be used afterwards to extract the relevant information such as:
 - Range of movement,
 - Linear and angular velocity, momentum and centre of mass of each segment,

- Mechanical energy expended,
 - Position, speed and angle of the implement at the instant of release.
- The results will be formatted in a short report that will be provided to coach and athlete the next day.

The main outcome of such analyses is to allow coach and athlete to make immediate educated choices, based on actual data, in relation to changes in throwing technique, physical preparation and possible future frame design. These analyses are also helpful to clearly identify and prioritise the research focus to be conducted in experimental conditions and during real-events.

For example, an analysis conducted on the Australian world-record holder in the class F34 men, during a training session 14 days prior the Athens 2004 Paralympic Games, revealed that he released the put 0.49 m/s slower compared to his own World Record. This information was critical to reorganise his training regime for the following two weeks aiming to increase his physical capacities to release the put faster.

However, such analyses presented a number of limitations:

- 2D kinematic data does not provide information for motion in the transverse plane. Throwing techniques involving a significant rotation in the transverse plane will therefore require 3D analysis.
- The understanding of forces and moments responsible for kinematic displacements will also be needed for a complete biomechanical analysis. These parameters can only be measured in a laboratory equipped with a force-plate and a tridimensional motion analysis system.
- These analyses may only be partially representative of the technique performed by elite athletes while competing in a world-class event. It is difficult to fully replicate the environment of a world-class competition, which often includes the stress and pressure due to the presence of other opponents, mass-media, referees in charge of applying the rules strictly, the use of official equipment, etc.
- Furthermore, analyses conducted either during training or in the laboratory rely only on a limited number of participants in a given class. Consequently, it is important to also record during real events, to have a more realistic understanding of the performance and also to establish intra and inter class correlations based on sufficient number of athletes.

4.3. Practical example

This section provides a practical example of the research conducted in the three different testing environments. Several topics were investigated, as presented in Table 2.

*** Insert Table 2 here ***

However, the determination of the optimal foot placement during the discus throw for an elite F34 Australian athlete will be discussed here. Foot position is a key factor of the performance as it determines the load profile of the external forces. This will be presented in a scientific format including aims, methods and outcomes sections. However, special emphasis will be placed on the methods section as some of the results have been analysed already.

4.3.1. Video recording during training

4.3.1.1. Aims

Over seven recording sessions were conducted during training. The typical aims of the recordings for each session were:

1. To provide immediate feedback to the coach and athlete via video footage
2. To try a maximum of 10 feet positions that felt the most efficient, based on trial and error

4.3.1.2. Methods

Population. One emerging and two elite F34 throwers participated in the recording.

Equipment. The video recording was conducted with a portable system including two digital cameras connected to a laptop. Both views were synchronised and recorded directly onto the computer as AVI files, with a sampling rate of 50 Hz, using DartFish software.

Setup. The cameras were placed on the side and behind the thrower, approximately 1.10 m high, at a distance between 5 to 12 m perpendicular to the axis of the plate used to anchor the throwing frame to the ground. The angle between the optical axis and the ground was approximately 90°. The field of view included the full-length (2.29 m) and full-width (1.68 m) of the plate and was enlarged in the direction of the throw to ensure the recording of at least the five first frames of the aerial trajectory, for the camera on the side. This field of view was obtained by zooming to reduce the perspective error once the cameras were positioned with respect to the plate.

Recording. The duration of the video recording of each attempt was approximately 7 seconds. The recording started when the coach handed the implement to the athlete, and ended shortly after it landed on the ground. A simple calibration frame made of two perpendicular sticks was used at the beginning and end of each recording session.

Procedure. The nature of this research required a particularly flexible protocol that allowed a faster response in order to accommodate the coaches’ and athletes’ demands. For example, no passive markers were placed on the athletes and the procedure consisted of trying out a number of feet positions. Sometimes this was done by physically altering the foot plates (if the throwing frame allowed for this), or

by holding a foot in a given position (Figure 4).

*** Insert Figure 4 here ***

Analysis. The biomechanical analysis focused on the correlation between the speed of release and

- (A) the segmental angles in the sagittal plane of the lower limbs and;
- (B) the hip and upper limbs movement pathway.

4.3.1.3. Outcomes

The results of the visual and biomechanical analyses were provided to coaches in a short report. Furthermore, the two main outcomes of the recording were:

- The selection of a maximum of five key feet positions to be tested in experimental settings,
- A set of parameters to extract from video recording during real-events.

4.3.2. Experimental setup in laboratory

4.3.2.1. Aim

All three testing sessions at the AIS laboratory focused on foot placement. The aim of the testing in an experimental setting was to establish a link between parameters of the discus’ trajectory at the instant of release and

1. The forces and moments applied at the point of contact of the athlete with the throwing frame (left foot, right foot and knee),
2. Kinematic characteristics (range of movement, linear and angular velocity, momentum and the centre of mass of each segment, as well as the mechanical energy expended).

4.3.2.2. Methods

Population. Two elite F34 throwers participated in the recording.

Equipment. The AIS’ motion analysis laboratory is equipped to collect kinematics and dynamics data. An overview of the experimental setup is presented in Figure 5 below. This included;

- 1 Kistler force-plate (1,080 Hz) measuring the total external forces and moments,
- 2 load cells (100 Hz) with six degrees of freedom, measuring the forces applied under each foot,
- 2 Redlake high-speed digital cameras (250 Hz) needed to determine accurately the moment of release of the discus and
- 1 Vicon tridimensional motion analysis system (120 Hz) providing the 3D coordinates of distal and proximal extremities of each segment.

*** Insert Figure 5 ***

All systems were synchronized using a common external pulse. A fully adjustable throwing frame allowing two load sensors to be mounted under the

feet was built especially for this experiment. In addition, a net placed was erected from floor to ceiling in front of the thrower to catch the discus after release.

Setup.

1. The throwing frame was strongly anchored on top of the force-plate.
2. The two load cells were mounted to the throwing frame using customized metal plates and foot straps. The coordinate system of each load cell was collinearly aligned with the coordinate system of the force-plate.
3. The six cameras of the motion analysis system were placed around the force-plate (three on each side). No camera was placed in front of the thrower to avoid collision with the discus.
4. Two high-speed cameras were placed on the throwing side and behind the force-plate.
5. The origin of the Global Coordinate System (GCS: O[ML, AP, V]) was located at ground level, in the middle of the force-plate and ahead of the thrower.

Procedure. Anthropometric measurements such height, weight, length and circumference of each body segment were taken. A total of 35 reflective markers were placed on the thrower so that each body segment was represented by a distal, proximal and third marker. Two additional markers were also placed on the discus to track the beginning of the flight after release. The thrower was asked to get onto the throwing frame and to throw at his maximal capacity. All the instruments started recording when the operator handed the discus to the athlete, and ended shortly after it hit the protective net. The thrower was asked to perform ten throws in each of the 5 feet positions. Sufficient rest was allowed in between trials to avoid fatigue. A calibration of the motion analysis system and the high-speed cameras was conducted at the end of the recording session.

Analysis. The kinematic and dynamic data were analysed separately using customized Matlab software. Firstly, the summation of the forces and moments provided by the load cells were subtracted from the total forces and moments provided by the force-plate, giving the load applied by the knee. Then, the loading profile at the three points of contact between the thrower and the frame (left foot, right foot and knee) was plotted. An example is provided in Figure 6. Particular attention was paid to the magnitude of the load at these contact points at the instant of release. Secondly, the 3D coordinate of each marker was associated to anthropometric information to determine the centre of mass of each segment and of the whole body. The range of movement, the linear and angular velocity and momentum of each segment and the centre of mass, the mechanical energy expended, as well as the position, speed and angle of the discus at the instant of release were also computed.

4.3.2.3. Outcomes

Preliminary results showed that it is possible to measure differences in external forces and moments applied by the athletes between feet positions. Scientific articles focusing on the methods and theory are currently in preparation.

In addition, the frame made specifically for the testing is now used as a training tool, allowing quick changes if needed.

*** Insert Figure 6 here ***

4.3.3. Video recording during real event

4.3.3.1. Aims

The aim of this video recording (during the 2002 IPC World Championships held in Lille), was to establish a link between the feet position and the performance of elite athletes.

4.3.3.2. Methods

Population. Twelve discus throwers in classes F33/34 competing in the 2002 IPC World Championship participated in this study. A total of 49 attempts were analysed.

Equipment. The video recordings were conducted with the same portable video system and software as the one used during training, as described previously.

Setup. The filming set up from the field of play during the Sydney 2000 Paralympic Games and the 2002 IPC World Championships was similar to the one used during training. However, adaptations were required to compensate for the many extra constraints imposed on such data collection, mainly because the recording was required to be systematic (16, 17). For example, a retake of a performance was impossible and every attempt of each athlete must be recorded in order to capture the best performances. The recording could not interfere in any way with the athletes, the officials, the referees or the TV crews. For instance, no active or passive markers were placed on the athlete. The camera views could be obstructed at any time by several factors, as mentioned above. Consequently, attempts were made to place the cameras relatively close to the plate in order to reduce the possibility of intrusion in the field of view from TV crews, other equipment and/or referees. The zoom was occasionally used to optimise the appropriate field of view. Furthermore, the position of the cameras could not interfere with any of the other on-going athletic events.

Analysis. The 2D coordinates of the heel, top of the foot and ankle of the front and back foot, were tracked frame-by-frame. A scaling, based on a calibration frame, allowed the three positions of these markers to be determined. A qualitative analysis focused on the number (left foot, right foot, knee, bottom, arm-rest) and type of contacts (strapped, locked, tucked). A qualitative analysis included the position of the feet, the distance and angle between the feet. All these parameters were plotted against the performance.

4.3.3.3. Outcomes

An example of the performance against resultant, vertical, antero-posterior and medio-lateral components of the position of the back and front foot for all attempts is provided in Figure 7.

*** Insert Figure 7 here ***

Results showed that there was no definite link between feet position and performance. The data did confirm however, that feet position is related to each athlete’s functional level and physical ability, and that each athlete’s technique as a result, is unique and individual. This reinforces the need for testing in experimental conditions to find the optimal feet position for a given athlete.

Methodological aspects and some of these results have been published and presented in scientific conference and reviews (16-20).

5. Practical implications

This applied research, as initiated by the Australian working group, has direct practical implications on the performances of Australian seated throwers. It is difficult to allocate their current success solely to this approach, as indicators of performance are so multi-factorial. However, the level of performance has constantly improved for the vast majority of the team since 2000. Thus, it is only fair to state the biomechanics conducted in the evidence-based approach has not impacted negatively in any way.

In addition, this applied research has indirect implications for all those involved in seated throwing events including:

- Sport scientists who can use the range of data provided to improve the modelling and the prediction of the performance.
- Coaches and athletes who can enhance training methods and throwing frame design.
- Coach educators who can enhance and update current curriculum in the area of seated throwing.
- Classifiers who can verify the true compliance of the athlete during the classification process and validate the classification system by conducting intra-class analyses.
- Referees who can use the video recording during the event to see if the athletes’ technique follows the rule lay down by the IPC. The footage could be used to settle possible athlete protests against referees’ decisions. This was experienced during the Sydney 2000 Paralympic Games where our tapes were required on several occasions by referees needing to review their decision.

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Table 1. Summary of the classification system and functional outcomes for seated throwers in Classes 52-58 (8). The Standard Muscle Charting is a series of functional and anatomical tests that indicate a level of disability in an athlete.

| Class | Functional outcomes |
|-------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| F52 | <ul style="list-style-type: none"> • Have difficulty gripping with their non-throwing arm • Unable to spread their fingers apart • May have the ability to flex and extend their fingers |
| F53 | <ul style="list-style-type: none"> • Have close to normal grip strength with throwing arm • Can spread fingers apart • Have full power at elbow, wrist and finger joints |
| F54 | <ul style="list-style-type: none"> • Display no functional trunk movement • Have no sitting balance • Usually grip onto wheelchair while throwing |
| F55 | <ul style="list-style-type: none"> • Use forward and backward movements • Display fair sitting balance • Ability to perform three specific trunk movements • Have normal upper limb function • May not have functional hip flexors • Display no adductor function |
| F56 | <ul style="list-style-type: none"> • Very good balance • Good forward and backward movements • Good trunk rotation • Able to perform hip flexion and adduction • Able to perform knee extension and flexion |
| F57 | <ul style="list-style-type: none"> • Can extend one of their hips • Able to bend one ankle downwards • Excellent balance • Excellent backwards, forwards and sideways movement |
| F58 | <ul style="list-style-type: none"> • Minimally disabled athletes • Do not exceed 70 points in the Standard Muscle Charting |

Table 2. Summary of four primary and secondary associated topics of research in biomechanics conducted during training, experimental testing and real event. The modifications of the throwing frame implemented for 12 Australians elite seated throwers are directly associated with the secondary topics. (1) mainly associated with Classes 52 – 56, (2) mainly associated with Classes 57 – 58, and 32 – 34.

| Primary | Secondary |
|----------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Seating arrangements (1) | <ul style="list-style-type: none"> • Strapping systems • Orientation of the seating area • Height and angle of back rest • Leg and trunk positions |
| Design and usage of the pole | <ul style="list-style-type: none"> • Energy storage propriety • Position and orientation within the frame • Handling mechanisms • Number of preparations prior the throw |
| Points of contact with the frame (2) | <ul style="list-style-type: none"> • Foot placements • Load applied by both feet • Load applied by the knee |
| Overall body position during the throw | <ul style="list-style-type: none"> • Hip placement • Position of body segments • Speed of upper limbs at release |

Figure 1. Example of a throwing frame used by an Australian athlete competing in Class F34 featuring a pole (A), seating area (B), knee strap (C), points to anchor the frame to the plate (D), foot rests (E) and wheels to manoeuvre the frame (F). Some frames also include a back rest. Location of the origin of the Global Coordinate System (CGS: O[V, ML, AP]) on the plate (G).

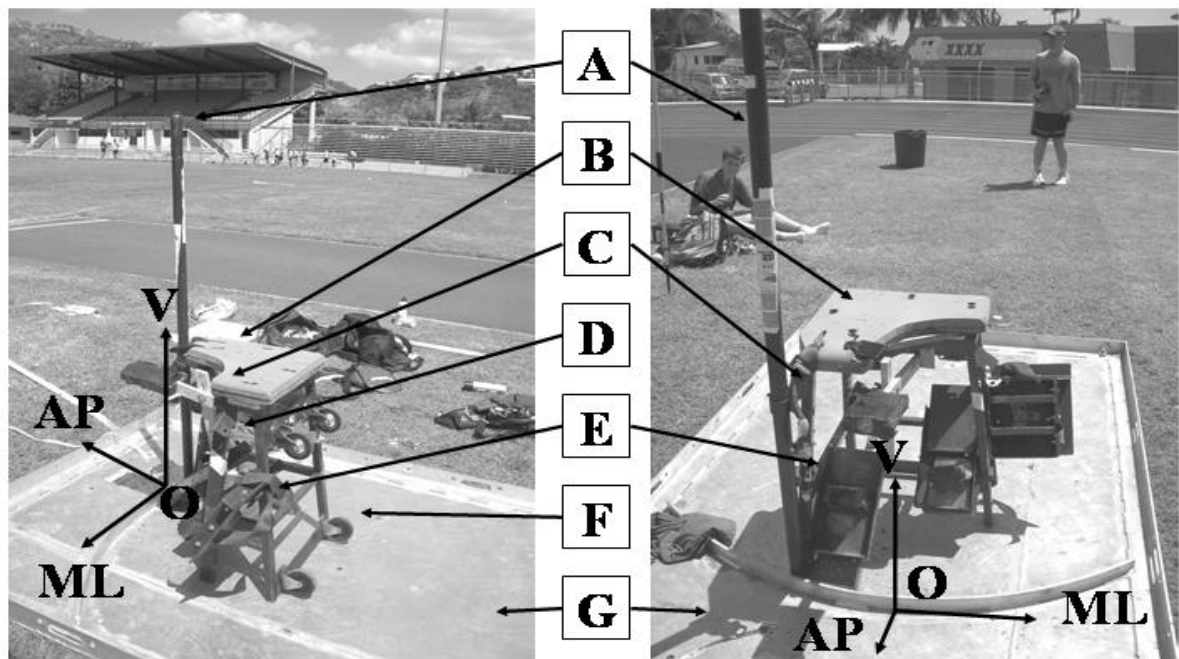


Figure 2: Overview of conventional and innovative integrated approaches underlying the current fundamental and applied research in biomechanics of the elite seated throwers.

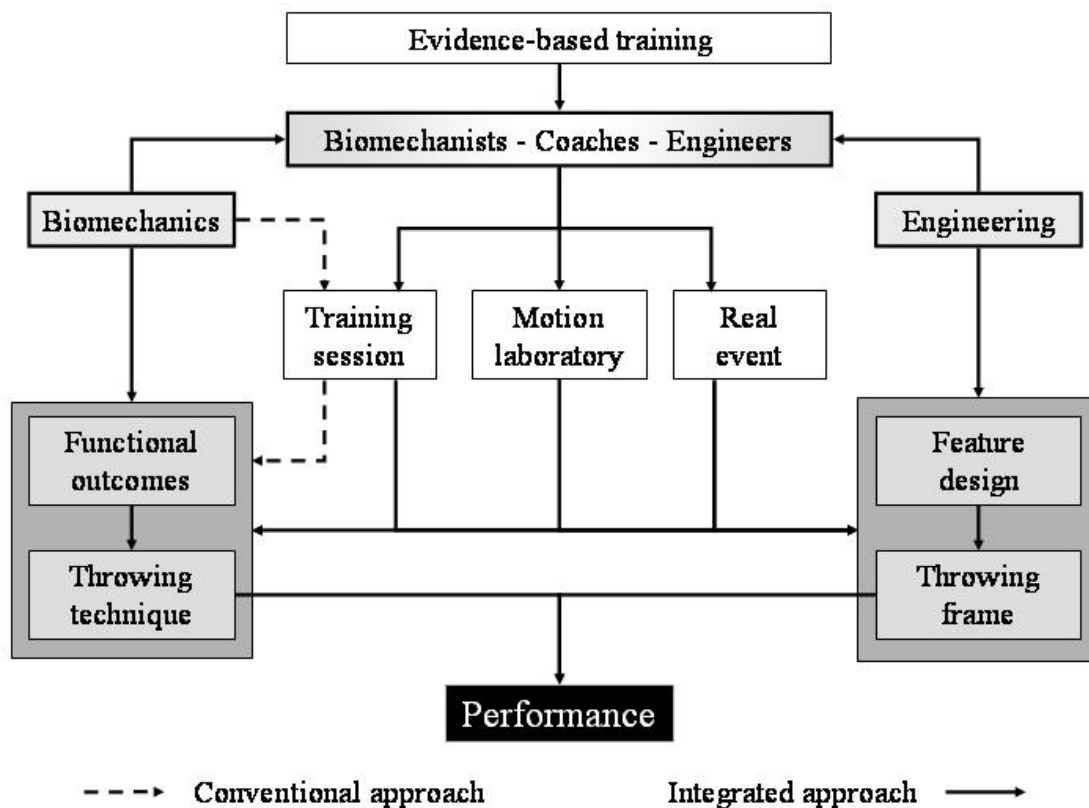


Figure 3: Overall dynamic research procedure including data flow and key players (AA: Athletics Australia, IPC: International Paralympic Committee, QUT: Queensland University of Technology, AIS: Australian Institute of Sport) of the integrated approach. Section A provides the ranking on the three research environments (laboratory, training and competition) on an subjective scale including the testing constraints, from closed to opened, in relation to the information output from accurate to realistic. Section B details the dynamics of research procedure placing testing during training in the centre, while testing in laboratory and competition are complementary. Section C details the outcomes in terms of articles and reports.

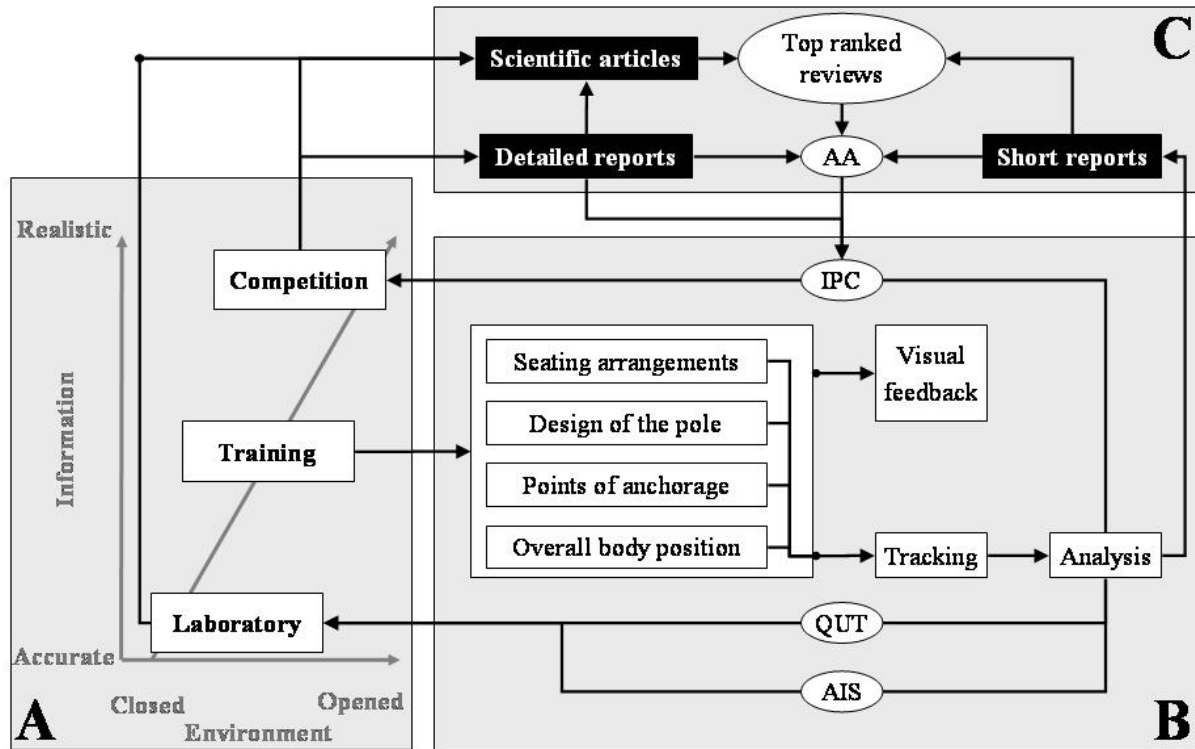


Figure 4. Example of manual adjustment of foot placement. The coach is holding the foot in a given position.



Figure 5. Typical camera set up used for research in experimental environment. A: passive markers, B: Knee strap, C: Right foot plate and load cell.

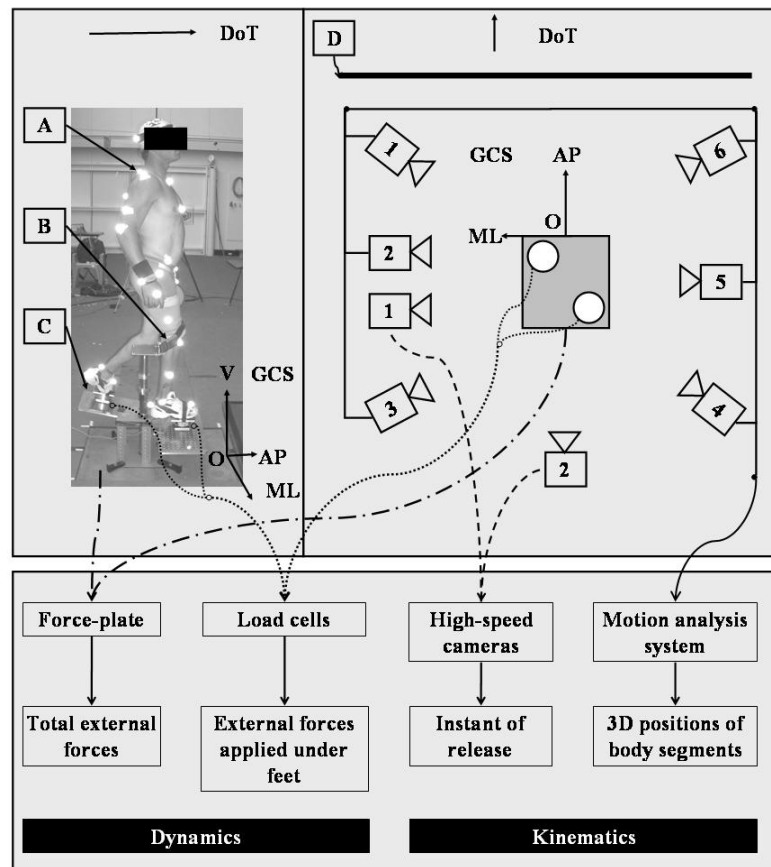


Figure 6. Norm of the forces applied on the points of contact between the athlete and the throwing frame (LC1: load cell 1, LC2: load cell 2, KN: knee, FP: force-plate).

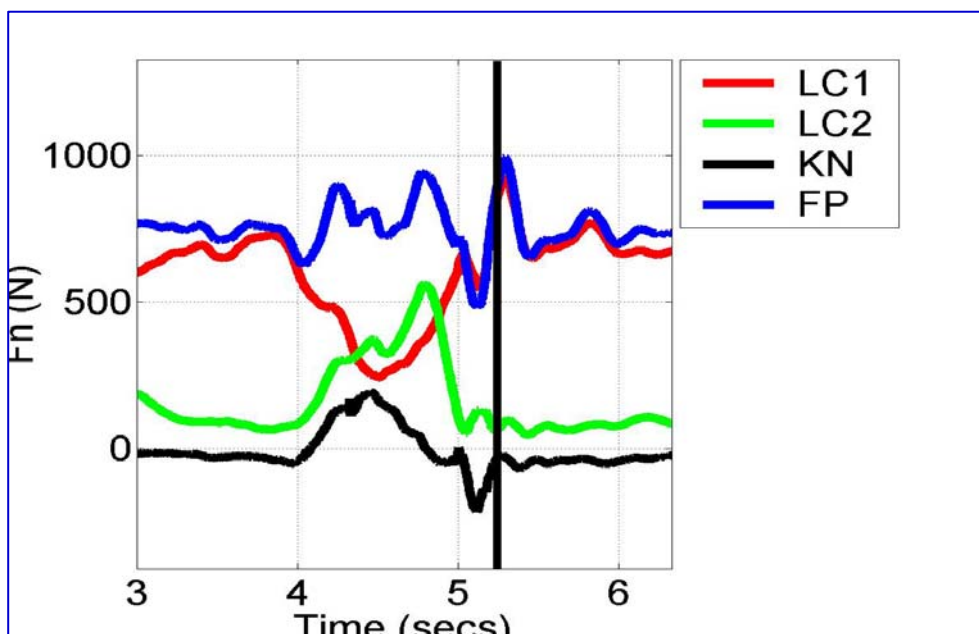


Figure 7. Performance vs resultant and vertical, antero-posterior and medio-lateral components of the position of the back and front foot all the attempts of the athletes in the classes F33/34 competing in the 2002 IPC World Championships.

