# Women's Hammer Throw

## Measurement Information System
## And
## Kinetic Energy of Body Segments and Hammer Head

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## Abstract

The hammer throw is one of the most attractive and complicated events of track and field. Researches still have hand in improving out about throwers performance by online and offline motion analysis methods for biomechanical deep insight. The current study involved two parts:

The First was emanated from the concept of transferring kinetic energy (KE) sequentially through the human body, which is an influential concept in biomechanics literature. Therefore, the current study is considered the first to quantify the KE of the throwers body segments (BSKE). Henceforward, the main objectives were to study: 1) kinetic energy of each of hammer head (HHKE), throwers body (BKE), and of each body segment, 2) the correlation between the BSKE and both of BKE and HHKE, 3) the segmental sequence of the KE, 4) predict HHKE by each of BSKE and BKE in release phase, and 5) the difference between the output BKE and HHKE in the release phase.

The second was to develop a Measurement Information System (MS) for measuring the accelerations, the angular velocities and the strain force in the wire to help coach and thrower during the training session to evaluate the performance.

Betty Heidler and Kathrin Klaas, top elite german hammer throwers, participated in the study. They were asked to perform six throws. For video capture, 5 digital high speed cameras (Casio Exilim Ex-F1) were used with frame rate of 300 f/s. The MS was bended to athletes and turned on during the throws. Simi Anthropo Model version 1.2 was used for calculating body segment masses and the location of center of mass, and Simi 3D Motion Program version 7.5.300 was used for motion analysis. The output data from MS was converted and calculated after synchronizing the data with video. The kinetic energies of thrower's body, each body segment, and of the hammer head were calculated and treated statistically.

Findings showed the BKE and HHKE increment and decrement stages happened consecutively not simultaneously. BKE increment stage (HHKE decrease) happened in the duration from LP to HP and BKE decrement stage was from HP to LP in all turns. It shows also that the difference among the values of HHKE in all trials appeared in the $LP_4$-R phase, where the greatest values of HHKE were for the farthest throwing distance. The BKE achieved the highest values before the $LP_4$ then decreased sharply afterwards. Accordingly, the higher the mathematical difference between the BKE and HHKE at release phase is, the better the achieved distance is .It was found also that the right leg kinetic energy (RLKE) was the greatest peak value then Left leg kinetic energy (LLKE) among the BSKE during all phases, with regard to the distinguishes due to the individual performance. The peak of the lower torso kinetic energy (LTOKE) and (UTOKE) was happening parallel with an indication of a slight twist between the UTO and LTO, that referes to useing the torso as solid lever to transfer energy from point to point. Each of the RLKE and the LLKE were the most effective segments on the BKE. The stepwise regression analysis revealed differences between the trials groups and between the individual performances of the two athletes as well. The body segments number that interacted significantly with the HHKE during the $LP_4$-R phase varied from trial to trial. Henceforward, the prediction equations also did not show a specific tendency. It is recommended to increase the base of research collecting data from more athletes in different levels, in order to be able to generalize the result.

The output data of acceleration and angular velocity, which were measured by MS, showed great similarity with the output from motion analysis (MA). The values were mostly identical in strain force case. In addition, the MS output curves were smoother than those from motion analysis (MA) with exception of the angular velocity output. The devise has proved its eligibility to sense various throwing levels. Therefore this device enables the user to make the possible comparisons between the individual performances simply and obviously and feed the coach and the thrower with the basic data of the throw. The future work is to recalibrate the gyroscopes and complete programming the software to be a compatible system for coaches and throwers use.

## Zusamenfassung

# Hammerwerfen

### Mess-Informations-System

### und

### kinetische Energie von Körpersegmenten und Hammerkopf

Der Hammerwurf ist eine der attraktivsten und kompliziertesten Sportarten der Leichtathletik. Forschungen tragen immer noch zur Leistungsverbesserung der Hammerwerferinnen durch online- und offline-Methoden der Bewegungsanalyse für biomechanische tiefe Einblicke bei. Die vorliegende Studie beinhaltete zwei Teile:

Der erste Teil ging vom Konzept kinetischer Energie (KE) aus, die dauernd durch den menschlichen Körper übertragen wird. Dies ist ein maßgebliches Konzept in der biomechanischen Fachliteratur. Deshalb will die vorliegende Studie zuerst die kinetische Energie der Körpersegmente (BSKE) der Hammerwerferinnen messen. Deshalb waren die zu untersuchenden Hauptziele folgende: 1) die kinetische Energie von jedem Hammerkopf (HHKE), des Körpers der Hammerwerferinnen (BKE) und jedes Körpersegmentes, 2) die Korrelation zwischen BSKE sowie BKE und HHKE, 3) die segmentweise Folge der KE, 4) die Vorausberechnung von HHKE durch sowohl BSKE als auch BKE in der Lösungsphase und 5) die Berechnung des Unterschieds zwischen dem Output BKE und HHKE in der Lösungsphase.

Der zweite Teil der Studie umfasste die Entwicklung eines Messungs-Informations-Systems (MS) zur Messung der Beschleunigungen, der Winkelgeschwindigkeiten und der Beanspruchungskraft bei der Übertragung, um Trainer und Hammerwerferin während der Trainingseinheiten bei der Leistungsbewertung zu helfen.

Betty Heidler und Kathrin Klaas, deutsche Spitzenhammerwerferinnen, nahmen an der Studie teil. Sie wurden gebeten, sechs Würfe auszuführen. Für die Videoaufnahme wurden fünf digitale Hochgeschwindigkeitskameras (Casio Exilim Ex-F1) mit einer Bildfrequenz von 300 f/s verwendet. Das MS war den Athletinnen angepasst und während des Werfens angeschaltet. Das Simi Anthropo Modell Version 1.2 wurde zur Berechnung von Körpersegment-Massen und der Position des Massenschwerpunktes verwendet. Das Simi 3D Bewegungsprogramm, Version 7.5.300 wurde für die Bewegungsanalyse verwendet. Die Ausgabedaten der MS wurden umgewandelt und nach dem Synchronisieren der Daten mit dem Video berechnet. Die kinetischen Energien des Körpers der Hammerwerferin, jedes Körpersegmentes und des Hammerkopfs wurden berechnet und statistisch ausgewertet.

## Zusamenfassung

Die Ergebnisse zeigten die Zunahme von BKE und HHKE, und Verminderungsstufen erfolgten aufeinander folgend und nicht gleichzeitig. Die BKE-Zunahme (HHKE-Abnahme) geschah während der Dauer von LP bis HP, wohingegen BKE-Verminderung von HP bis LP bei allen Drehungen auftrat. Es zeigte sich auch, dass der Unterschied zwischen den Werten der HHKE in allen Versuchen in der LP4-R Phase auftrat, wo die höchsten Werte der HHKE bei der größten Wurfentfernung auftraten. Die BKE erreichte die höchsten Werte vor der LP4, danach fielen sie stark ab. Daraus folgt, je größer der mathematische Unterschied zwischen der BKE und HHKE in der Lösungphase ist, desto besser ist die erreichte Entfernung. Es zeigte sich auch, dass die kinetische Energie des rechten Beins (RLKE) den größeren Maximalwert als die kinetische Energie des linken Beines (LLKE) unter der BSKE während aller Phasen hinsichtlich der Unterschiede der individuellen Leistungen hatte. Die Spitze der kinetischen Energie des unteren Rumpfes (LTOKE) wurde mit der des oberen (UTOKE) erreicht, was bedeutet, asdd den Rumpf als festen Hebel verwendete wurde, um Energie vom Punkt zu Punkt übertragen.

Sowohl RLKE als auch LLKE waren die wirksamsten Segmente auf die BKE. Die schrittweise Regressionsanalyse zeigte Unterschiede zwischen den Probandengruppen und ebenso zwischen den individuellen Leistungen der zwei Athletinnen. Die Anzahl der Körpersegmente, die signifikant mit der HHKE während der LP4-R Phase aufeinander wirkte, änderte sich von Versuch zu Versuch. Künftig zeigten die vorhergesagten Gleichungen auch keine spezifische Tendenz. Es wird empfohlen, die Basis von Forschungsdaten von mehr Athleten verschiedenen Niveaus zu vergrößern, um im Stande zu sein, das Ergebnis zu verallgemeinern.

Die Ausgabedaten der Beschleunigung und Winkelgeschwindigkeit, die durch die MS gemessen wurden, zeigten große Ähnlichkeit mit dem Ergebnis der Bewegungsanalyse (MA). Die Werte waren in der Beanspruchungskraft größtenteils identisch. Außerdem waren die MS-Ergebniskurven glatter als diejenigen der Bewegungsanalyse (MA) mit Ausnahme des Ergebnisses der Winkelgeschwindigkeit. Die Methode hat ihre Eignung bewiesen, um verschiedene Wurfniveaus zu untersuchen. Deshalb ermöglicht diese Methode dem Benutzer, die möglichen Vergleiche zwischen den individuellen Leistungen einfach und sichtbar zu machen und dem Trainer und der Hammerwerferin die grundlegenden Daten des Wurfes an die Hand zu geben. Die zukünftige Arbeit soll die Gyroskope rekalibrieren und die Software vollständig programmieren, um ein kompatibles System für Trainer und Hammerwerferinnen zu sein.

# Contents

# Abbreviations

| | |
|---|---|
| KE | Kinetic Energy |
| MS | Measurement Information System |
| H or thrower H | Betty Heidler |
| K or thrower K | Kathrin Klaas |
| SFS | Strain Force Sensor |
| DS | Double Support Phase Of Hammer Throw |
| SS | Single Support Phase Of Hammer Throw |
| Hp | High Point Position Of Hammer Head Which occurs During SS |
| LP | Low Point Position Of Hammer Head Which occurs During DS |
| BSKE | Body Segments Kinetic Energies |
| HHKE | Hammer Head Kinetic Energy |
| HKE | Head Kinetic Energy |
| UTOKE | Upper Torso Kinetic Energy |
| LTOKE | Lower Torso Kinetic Energy |
| RAKE | Right Arm Kinetic Energy |
| LAKE | Left Arm Kinetic Energy |
| RLKE | Right Leg Kinetic Energy |
| LLKE | Left Leg Kinetic Energy |
| MA | Motion Analysis |

# 1 Introduction

The hammer throw event is one of the most attractive and complicated of the track and field events. The sources of modern hammer throwing are hidden in the distant past as combination of work, leisure and warfare. During the 18th and 19th centuries in Ireland and Scotland, where the ancient traditions live, throwing hammer was the sport of farmers and workers. Outstanding rulers and politicians of the middle ages were given partly derived from their throwing abilities. Eadweard Muybridge did probably the first movement study by sequence photographs of hammer throw. Athletes with an Irish background advanced the world record 33 times from 1877 until 1937 and won gold medals at five Olympic Games. The rules of the implements in modern competitive hammer throwing were laid down in 1887 in the USA (Bartonietz, 2000).

Throwing hammer event is historic event for men, while the men have been throwing the hammer for centuries and last world record was before 26 year, unlike women who have a relatively short history in the event. Wagner (2006) noticed that women's hammer throwing was not ratified until 1995, however being recognized in several countries prior to its ratification. Several women began to throw the hammer in the 1980s, like Cheryn Ison, who threw over 42 m in NS. Women's hammer throw was added to the World Championships in 1999. The record has grown rapidly behind the 70 meter mark, in spite of the event's short history. Several elites such Olga Kuzenkova (RUS), Mihaela Melinte (ROM), were the early pioneers of the sport, they set the first 14 world records (Kuzenkova 6, Melinte 8). Recently since 2009, Betty Heidler (GER) and Anita Wlodarczyk (POL) lead the women record. In the last 12 years the world record is broken 7 times (see table 1) even in 2006 it had been broken 3 times. It refers that the women still have more to show in the future.

For the previous reason the studies are still focusing on men's hammer throwers, except some publications which focused mainly on women's technique and studying the difference between men and women in hammer throw, which due the differences to morphological differences and implement's weight and length. They may be try to find a way for further progress and a new world record after 26 years. Riley et al. (2005) referred, from their point of view, to the lack of research which hinders evolution of hammer, they illustrated the efforts of researcher specially Jesus Dapena, who began a set of biomechanical publications that served understanding technique and going further with the kinetics of throwing hammer and his publications are considered educational at the same time. Most of researches are considered as diagnostic studies and added something valuable to the literature. In my opinion the lack was in the kinetically studies except few of them. Henceforth the researches started to go towards the kinetically diagnostic studies for the source of the forces trying to reexamine some parameters or trying to develop the technique or the physical requirements to serve the performance. Since the common and popular attitude to find the reason of lack performance is to quantify the hammer head, thrower center of mass and the common center of mass parameters. Tthe current study is then a piece of the hammer throw knowledge puzzle biomechanical picture by studying the kinetic energy of hammer head and the first piece of quantifying the body segments movement of hammer thrower.

Table 1. Women Hammer Throw world record progress

| Year | World Record (m) | Record Holder | Placement at Oympic Games and distance(m) | | |
|---|---|---|---|---|---|
| | | | 1st | 2nd | 3rd |
| 1997 | 73.1 | Olga Kuzenkova (RUS) | | | |
| 1998 | 73.8 | Olga Kuzenkova (RUS) | | | |
| 1999 | 76.07 | Mihaela Melinte (ROM) | | | |
| 2000 | 75.68 | Olga Kuzenkova (RUS) | 71.16<br>Kamila Skolimowska | 69.77<br>Olga Kuzenkuva | 69.28<br>Kirsten Münchow |
| 2001 | 73.62 | Olga Kuzenkova (RUS) | | | |
| 2002 | 73.07 | Olga Kuzenkova (RUS) | | | |
| 2003 | 75.14 | Yipsi Moreno (CUB) | | | |
| 2004 | 75.18 | Yipsi Moreno (CUB) | 75.02<br>Olga Kuzenkova | 73.36<br>Yipsi Moreno | 73.16<br>Yunaika Crawford |
| 2005 | 77.06 | Tatyana Lysenko (RUS) | | | |
| 2006 | 77.26 | Gulfiya Khanafeyeva (RUS) | | | |
| 2006 | 77.41<br>77.8 | Tatyana Lysenko (RUS) | | | |
| 2007 | 77.3 | Tatyana Lysenko (RUS) | | | |
| 2008 | 77.32 | Aksana Miankova (BLR) | 76.34<br>Aksana Miankova | 75.20<br>Yipsi Moreno | 74.32<br>Wenxiu Zhang |
| 2009 | 77.96 | Anita Wlodarczyk (POL) | | | |
| 2010 | 78.30 | Anita Wlodarczyk (POL) | | | |
| 2011 | 79.42 | Betty Heidler (GER) | | | |
| 2012 | 78.69 | Aksana Miankova (BLR) | 78.18<br>Tatyana Lysenko | 77.60<br>Anita Wlodarczyk | 77.13<br>Betty Heidler |

The data taken from: Bartonietz 2000,
http//www.iaaf.org/statistics/toplists/inout=o/age=n/season=0/sex=W/all=y/legal=A/disc=HT/detail.html,
http://www.iaaf.org/statistics/records/inout=o/discType=5/disc=HT/detail.html
http//berlin.iaaf.org/results/racedate=082009/sex=W/discCode=HT/combCode=hash/roundCode=f/results.html#detW_HT_hash_f

Kinetic energy is the combination of the effect of the velocity and the mass, since the velocity and acceleration of hammer head was killed in search, but the effect of body mass on performance is still in search process. The combination between the velocity of each body segment and their masses may be another addition to the anthropometrical characteristics of throwers, as well as the contribution of each segment in the output energy that is presented in hammer head.

Every result needs approach method, it is useful to reexamine the biomechanical parameters, in order to see the progress of technique and try to track the change in the performance, using new measurement methods and technology or employ new physical theories. But it depends also on the researcher target. Most of studies targeted to describe the best performance, which could be possible not found but in competitions, especially international competitions and Olympic Games, where the motivation and thrower high form are found. On the other hand, some difficulties are found which may be affecting the result accuracy. They illustrated as following

- No chance of mounting body land markers.
- Few cameras may be 2 or 3
- The cameras are put from the circle center between 15 to 70m away.
- Recording the movies is from behind the nets. Therefore, the used cameras have to be very special and powerful lenses focal length and resolution.

The studies, which targeted to more accuracy and experimenting or testing measurement systems like the force plate form for example, have to come over the previous factors. Therefore the solution was to record the material during training session or even in a separate session, even they lose the chance to gain top performance and may be a new world record. But it can also be not bad if the participant is top elite hammer throwers, which means a stable performance, in addition choosing the good training season like pre competition season for example.

The next level is to think how to feed the coach/thrower back as fast as possible with the performance. To have the opportunity to correct the faults and improve the performance based on a quantified data not just experts eye, although it is very important.

Agostini et al. (2003), Murofushi et al. (2005), Ohta et al. (2008), and Brice et al. (2008) worked on this idea , which is how to develop a measurement system of hammer throw to give the immediate feed-back as possible while the throw is still fresh in the thrower head during training session. They used the technology starting from recording wind acoustic to reach using wireless and Microelectromechanical systems (MEMS) technology. Who know about the hammer, realize how it is difficult to use measuring systems else but wireless or portable systems for direct result output. Unfortunately, none of those systems were offered commercially, thus, it was necessary to manufacture the developed system first and test its validity. Therefore, the second part of the current is a developed system for measuring the 3D acceleration and 3D angular velocity as well as the strain force in the wire. During meeting coaches and some researcher in Germany, I found that no one knows about the previous versions of hammer measurement systems.

## 1.1 Objectives of the study

The purpose of the current study is to answer the following questions

1. What is the character of body kinetic energy, hammer head kinetic energy and body segments kinetic energy of throwing hammer during turns and release phase?
2. What is the sequence of transferring kinetic energy of body segments during turns?
3. What is the relationship between the body segments kinetic energies and both of total body kinetic energy and hammer head kinetic energy during turns and release?
4. Could we find out a specific set of body segments that interact to achieve a better distance?
5. Could we determine the transfered kinetic energy during release phase?
6. Is the measurement system valid to be used as a feed-back system for hammer thrower?

# 2 Literature Review of Kinetic Energy

The main subject in the current study is about one type of energy, kinetic energy, which would be the main point in the rest of the chapter. First, we should before refer widely to the mechanical energy as all**Mechanical energy**

The mechanical energy of the object is defined as" the capacity for doing work". It's also defined as "the ability to perform work or the ability to affect the state of the matter", in other words "energy is the motion of particles or the potential to create motion". It has several forms, they are kinetic energy, gravitational potential energy, and (unless the object is rigid) elastic strain energy, which is stored as a result of the deformation created by the applied force. The total mechanical energy $E_T$ of a rigid body is equal to the sum of its kinetic $KET$ (translational and rotational) and gravitational of potential energies $PE$(Abernethy, 2005).

$$PE = m.g.h \qquad \text{----------------1}$$

$$KET = Linear\ KE + Rotational\ KE = {}^{1}/{}_{2}\, mv^2 + {}^{1}/{}_{2}\, I\omega^2 \qquad \text{----------------2}$$

$$E_T = KET + PE \qquad \text{----------------3}$$

$$E_T = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2 + mgh \qquad \text{----------------4}$$

where $m$ is the mass, $v$ is the velocity, $I$ inertia, $\omega$ is the angular velocity, $g$ is the gravity, and $h$ is the change of the position of the moving body (Abernethy, 2005; Blazevich, 2007).

### 2.1.1 Chemical energy and mechanical energy

Depending upon the type of activity, about 70 % of the chemical energy may be converted to heat during physical activity, while the rest, relatively small amount, is converted to serve the movement. However, once the chemical energy is converted to mechanical energy in the muscles, the body is able to perform various physical tasks. Such physical tasks might range from involuntary tasks such as contraction of the heart muscle or the respiratory muscles to voluntary tasks such as writing or sprinting for the bus. Most of the mechanical energy generated by the body can be quantified (i.e. put in a numerical form) by examining the amount of useful done-work (Williams et al., 2008).

In the study of exercise and sport, it is possible to determine the amount of energy expended by an individual to perform a given task. The energy expended will be the sum of the useful work done and energy lost as heat and energy lost in other forms (e.g. sound). The total energy expenditure is usually measured in an indirect way through the examination of gas exchange at the mouth. If, for example, an individual expends 1000 kJ in order to run 5 km, it is interesting to examine what this amount of energy relates to in terms of an amount of chemical energy in the form of food. The ability to quantify energy expenditure is very useful in exercise and sport (Williams et al., 2008).

## 2.2 Potential energy (PE)

It is the first form of $E_T$, it has two sub-forms. One is **gravitational potential** energy (equ.1) which is the energy that is stored in an object because of position above the ground. The higher the object is , the larger its PE is. The second form of PE is **strain energy ($E_S$)** which is the stored energy due to the amount deformation and the stiffness (k) of a material. It is given by the equation (Grimshaw et al., 2006).

$$E_S = \frac{1}{2} k \, . d^2$$

As in most biomechanical studies, the body segments are considered rigid bodies, then we focus just on gravitational potential energy which is the energy associated with position.

## 2.3 Kinetic energy

It is the other form of $E_T$ which associates with motion. It has also two sub-forms, The first form is the **translational Kinetic energy** which expresses the done work to move an object linearly. For example, in the sprint start the sprinter has to supply muscle energy on each stride to increase the body's velocity. The energy is similar for each leg on each drive but the effect on the increase in the sprinter's velocity diminishes as speed increases (Grimshaw et al., 2006).

The first component at the right side of equation (2) indicates that a greater mass or velocity has a greater energy, but the increase in mass has less effect than an increase in velocity (i.e. the v is squared) and so faster-moving objects have a far greater kinetic energy (Blazevich, 2007). The second form of kinetic energy is termed **rotational (or angular) kinetic energy.** Most sports actions involve rotation of the limbs about a joint and so during these actions energy is contained in the rotation of the limbs. As joints flex and extend (e.g., the knee joint) the limb segments move forward and backward, changing their direction on each cycle (Grimshaw et al., 2006).

Usually muscular chemical energy is expended in performing actions, so it is required in order to both increase and reduce the kinetic energy. Thus, movements that involve a lot of starting and stopping (like games play or racket sports) also require high levels of chemical energy expenditure (Grimshaw et al., 2006).

## 2.4 Kinetic Energy for throwing events

Vrabel (1987) emphasizes that the best results in throwing Discus must be the aim of the thrower to strive for, can only be achieved by good balance and full utilization of the available force, which means to complete transfer of the kinetic energy into the discus. The behavior or the movements of the discus thrower just after releasing the discus can tell the coach a lot about how successfully the kinetic energy was transferred into the discus and at what balance conditions it was done. The ideal throw should be finished in perfect balance, which means in relatively stable position with a slight tendency to follow the discus. The complete transfer of all kinetic energy to the discus means there would be any rotational movement of the body after release.

The same is in the case of hammer throw, where the thrower has to accelerate the hammer gradually in turns and try to transfer whole (theoretically) or most of kinetic energy to the hammer at release and after the last DS.

Examining the relationship between the kinetic energy of the performance phases and the kinetic energy of the body segments could give indication about the most important phases of technique, which reflects the most working and participating segment for affecting the performance. As well as it would be as a criterion to evaluate the effectiveness of training. That what Wang and Zhao (2000) targeted with their studying of 8 of experienced Chinese-shot-putter in back-glide technique. They found that the technique in push-off phase is the most important and requires the maximum speed of the putter's upper body, and the maximum explosive power, speed and coordination. They were also able to identify the performance positions, where there is significance correlation between the individual values of kinetic energy of body segments with the individual values of the shot put result. That was, when the right foot leaves the ground, when it touches the ground, and at the end of push off. The authors also could also recognize the main phase (the gliding) that included the increase in energy translation between the potential and kinetic. In this search, the gliding phase and the beginning of push-off phase were the main phases of energy output by the shot putter. That refers to the effective work of the support leg with the free leg, and drives towards the stop board.

## 2.5 Effective factors on kinetic energy of throwing hammer

Silvester (2003) reports that the efficient transfer of energy to the implement takes place not only at release but also throughout the entire turns. Positioning the hammer carefully at different phases would enable a successful transfer before and at release moment. Kinetic energy as mentioned before depends on the half-mass of body and its squared-velocity. Therefore, the focus in the next part would be on hammer velocity in different performance phases and the masses of the thrower body.

Throwing hammer technique consisted of winds as preparation, entry, turns (3 to 5), and release and balance. Each turn divided into two support phases the single support (SS) and the double support (DS). In addition, there is two main positions of hammer head in each phase of the SS and DS, which are high point (HP) and low point (LP) positions, respectively. The thrower works on accelerating the hammer head gradually from turn to turn to be the greater at release. As the rest throwing events, throwing hammer has its optimal release height, velocity, and angle, which lead to best possible flying curve.

Biomechanists studied the performance from three considerations, which are thrower center of mass, hammer head, and the common center of mass of both of thrower and hammer. Dapena (1986) describes the motion of all three centers of masses of each (hammer, thrower, and system). He illustrated that the motion followed cyclic patterns with one fluctuation per turn on the vertical direction. The fluctuation of thrower center of mass was ahead of that of the hammer by approximately a third of a cycle, and this made the periods of upward vertical acceleration of systems' center of mass coincide approximately with the DS phases. The motion varied in the horizontal plane, where the thrower's and hammer's center of mass followed roughly trochoid[1] patterns as a result of the combination of rotation with forward displacement across the throwing circle. The system's center of mass followed a roughly trochoid pattern in approximate synchrony with either the hammer or an essentially straight trajectory.

There are two points in the hammer path, which not only draw the right acceleration path but also give the hammer gradually the best possible trajectory which determinate the height and the angle at the release. They are **High and Low points (HP & LP)** (Figure 3). These two points or positions relate closely to another definition ''azimuth angle'' (Figure2), this definition isn't used in the other throwing events but hammer throw, hence the azimuthal angle gives the position of the hammer head according to throwing circle in an overhead view (Dapena, 1986). As the thrower perform 3-5 turns end with release, it is helpful to impute the parameter to the azimuth angle, which refers to a position on the circle, which enables to get the right image of the position of the body and the hammer all over the turns. Murofushi (2007) presented his results as a function of azimuthal angle instead of time (Figure 1).

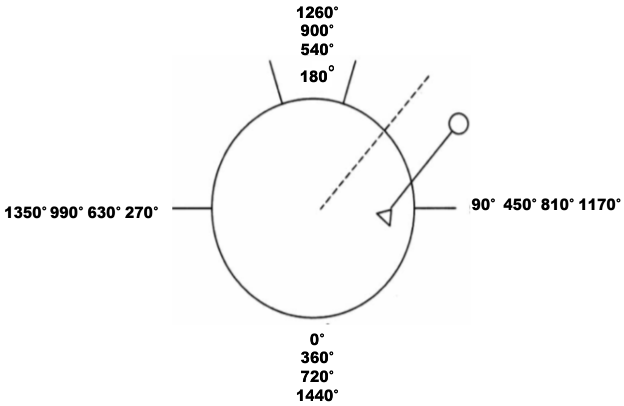



Figure1. A schematic diagram of the azimuth angle from 0° to 1440°,defined as the direction of the wire from the hammer handle to the hammer head and the rotation angle of parallel lines passing through the centre of the circle (Murofushi et al., 2007)

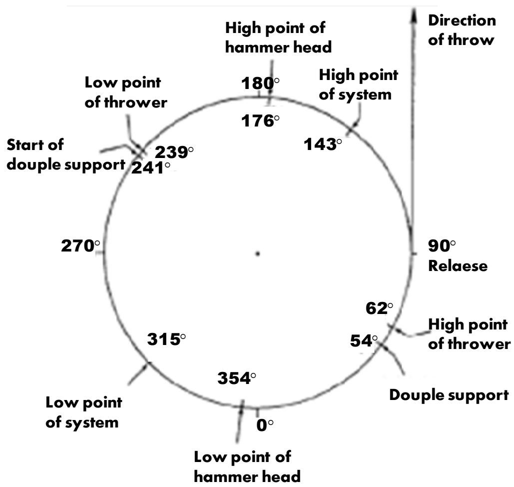



Figure 2. Overhead view of the hammer path. The numbers indicate azimuthal angles (Dapena, 1986)

[1]is the word created by Gilles de Roberval for the curve described by a fixed point as a circle rolls along a straight line. As a circle of radius *a* rolls without slipping along a line *L,* the center *C* moves parallel to *L,* and every other point *P* in the rotating plane rigidly attached to the circle traces the curve called the trochoid.

Dapena (1986) (Figure 2) illustrated the HP and LP of the hammer orbit with average azimuthal angles of 176° and 354°, respectively. These values are very close to 180° and 0°, respectively.

Furthermore, imputing the position of thrower's center of mass (c.m) also to the azimuth angles accompanied with the hammer head shows also the synchrony with each other. When the azimuth angle at the HP is almost the same as for the LP of the centre of mass, and the starting point of the DS phases occurred after the LP for the centre of mass that reveals advanced and controlled performance level.

Gutiérrez et al (2002) referred to the necessity to initiate the SS at 90º azimuthal angle or more, and to initiate the DS close to 250º or less, in order to increases the displacement of the hammer during the DS phase. Table (2) illustrates examples of the azimuthal values of elite female hammer throwers for top throws. The values of the first SS which refers to the entry specially differs from the mean of the other turns and differs from turn to turn. the azimuth angles in DSs around 250°. Which reveals the individuality of performance and the accompining them with support phases durations.

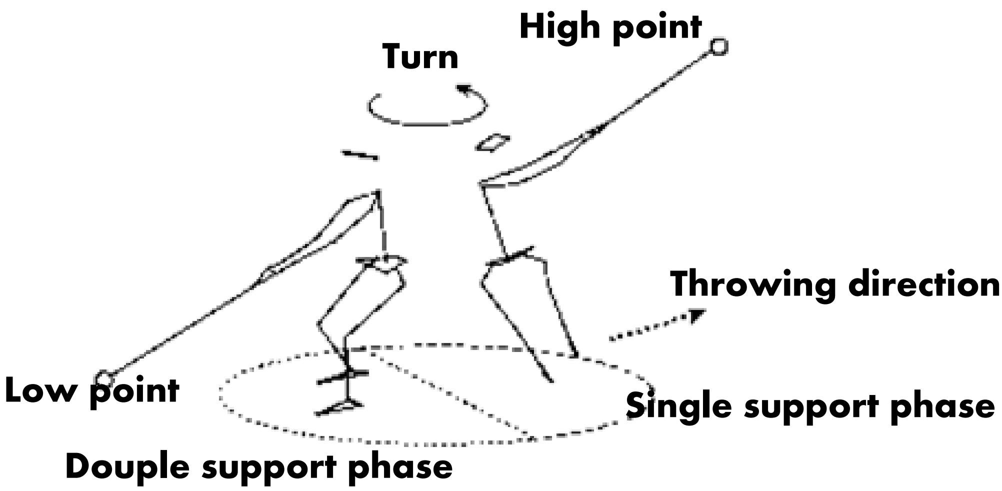



Figure 3. High and low points in one turn (Ohta et al., 2010)

Table 2. Values of the azimuthal angels of elite female hammer thrower at the beginning of each support phase.

| Athlete and Competition | Azimuth angle of the hammer head over the turns | | |
|---|---|---|---|
| | turns | SS | DS |
| Miheala Melinte (74.21m) (Sevilla 1999)[1] | 1st | 49° | 242° |
| | 2nd | 99° | 264° |
| | 3rd | 93° | 277° |
| | 4th | 70° | 277° |
| | release | 129° | |
| Olga Kuzenkova (72.65m) (Sevilla 1999)1 | 1st | 115° | 237° |
| | 2nd | 86° | 249° |
| | 3rd | 66° | 252° |
| | 4th | 78° | 263° |
| | release | 126° | |

[1] Gutierrez et al. (2002)

### 2.5.1 Acceleration and velocity of the hammer head and the thrower's center of mass

At the end of the second wind begins the entrance, where the hammer should be on the right side, the thrower's body weight should be on the left with the left shoulder slightly lower than the right. The thrower has to strive for a wide movement path of the implement going into the first turn, based on a flexible shoulder girdle. At this point, the thrower simultaneously drives the hammer across from the right side to the lefts side by keeping the left shoulder low and shifts weight from the left leg to the right leg as the hammer passes the LP. Once again, the LP should be between the feet. During turns, thrower is able to be in the correct power position, if he kept the majority of his weight on the left leg and countered the ball with a straight back. To accelerate the hammer, the thrower simultaneously drives the ball across through the LP by keeping the left shoulder low and actively pushing with the right leg, and the weight begins to shift from the left leg to the right leg (Bartonietz, 2000; McAtee and Stoikos, 2003).

When that translated to understand the kinetic energy and what it should be during this phase. It is expected that the BKE (Body Kinetic Energy) value less than HHKE (Hammer Head KE) in this power position and keeping the weight on the left leg in order to counter the HH. At the end of this phase, it supposes to notice increase in the RLKE (Right Leg KE).

Bingisser and Jensen (2011) and Judge (1999) adopt Dapena's (1986) suggestions about prolonging the DS phase duration against the SS, due to his study added to the Russian's interpretation in this field. The reason relied on that the body would be more stable and controlled by being the two feet on the ground, so the athlete has the opportunity to apply force as much as he can than being on one foot. In other words, it is to think in term of "distance of force application" to increase horizontal velocity. Therefore, they suggest taking advantageous by landing the right foot quickly as possible. Susanka et al (1987) monitored the need to shorten the temporal of the SS phase gradually, in order to make the SS and DS phases of the last two turns of equal length as an effective factor for accelerating hammer head and achieving distance. On the other hand, Morufushi (2007), Maheras (2009), Rojas-Ruizand Gutiérrez (2009) and Brice (2011) find that the thrower can accelerate the hammer in SS also. For instance, table (3) illustrates how the DS for some throwers were longer than SS duration was.

Table 3. The durations of SS and DS phases and the total duration of the throw beginning with the entry. these data is of hammer throw finalist in the world chamionship 1999 (Gutierrez et al., 2002)

| Athlete (Women) | **Phases in each turn (s)** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | SS,T1 | DS,T1 | SS,T2 | DS,T2 | SS,T3 | DS,T3 | SS, T4 | Release | Total |
| Mihaela Melint | 0.36 | 0.33 | 0.25 | 0.25 | 0.25 | 0.18 | 0.26 | 0.24 | 2.12 |
| Olga Kuzenkova | 0.28 | 0.37 | 0.27 | 0.24 | 0.26 | 0.23 | 0.24 | 0.26 | 2.15 |
| Lisa Misipeka | 0.34 | 0.41 | 0.27 | 0.29 | 0.23 | 0.23 | 0.26 | 0.26 | 2.29 |
| Katalin Divos | 0.32 | 0.32 | 0.28 | 0.22 | 0.30 | 0.22 | 0.30 | 0.27 | 2.23 |
| Lyudmila Gubkina | 0.26 | 0.35 | 0.26 | 0.25 | 0.27 | 0.21 | 0.27 | 0.24 | 2.11 |
| Simon Mathes | 0.30 | 0.36 | 0.26 | 0.24 | 0.26 | 0.22 | 0.26 | 0.20 | 2.10 |

From the point of view that optimal technique is the effective personal technique, wherein the athlete uses individually a combination of all his/her abilities to achieve a best record, Maheras (2009) refers to some attitudes to begin accelerating hammer head even before lying down the leg for DS. The researchers considered that as a technique mistakes, but it could be discussed further as a technical improvement, which the female throwers lay on it to achieve longer acceleration path, which by its role lead to achieve relatively higher release velocity. Hence further, the DS is considered as the main, but not the only, phase of accelerating hammer head.

Bingisser and Jensen (2011), Judge (1999), Maheras (2009) divide the DS into two parts according to azimuth angle first from 240˚ to 0˚, the feet are slightly ahead of the hammer while it is on its downward path, creating an ideal situation for increasing the hammer's velocity. The quick right foot contact using the rotating right foot initiates the hips and torso to serve as the mechanism to push the ball out and around the front of the body to 0˚. Another movement involves the landing of the right foot with the toe pointing towards the 270° azimuthal angle instead of the 0° angle. The second part of the work phase continues from 0˚ to 90˚. The athlete should let the ball run past the left leg by pushing with the right until the leg is lifted. There will be a whipping type of action with the ball. Continuing to work the ball from 0˚ to 90˚ keeps the ball from slowing down.

The initial velocity of hammerhead demonstrated the significant positive correlation with the performance. The velocity of hammer head was highest when passing around the lowest point from the ground and lowest when passing the highest point from the ground (Akira, 2005;Okamoto, 2008)

The mechanism of increasing hammer speed is a foot work or as output of the leg work, as a result of the active and continuous turning and never held in the DS (Susanka et al., 1986; Bartonietz et al., 1988).Accelerating the hammer head is by tangential and angular acceleration. The angular acceleration is resulted from a pushing force generated from the right leg during driving the hammer head down through the low point, while the tangential acceleration is resulted from countering the thrower against the hammer centripetal force (Judge et al. 2011). After landing, right foot is rotating as the upper body is countering back in the direction of throw. This is accomplished with a passive upper body. When the athlete catches the hammer, the violent counteraction occurs and the thrower accelerates the ball to 0˚ by countering against the hard heel. The lower body (hips and legs) must move faster and faster by pushing away from the hammer with a hard left heel grinding the right foot against the ground(Bingisse and Jensen, 2011; Judge, 1999).

According to the described technique above, HHKE suppose to be higher especially in the duration between the beginning of DS and LP. In addition, the RLKE also supposes to show high values of KE as being active foot. As well as the LTOKE should show an increment in the KE in this phase to push the HH towards and around LP. However, the passive upper body reflects the probability of the decrement of UTOKE during this phase.

Bartonietz et al. (1988) indicated that selecting talent should base on the concepts of the relatively lean boys with long arms, high mobility of the shoulder girdle and stretching strength of the legs. Wagner (2006) added that the strong legs and trunk are more important than strong shoulders, which should be regarded during the process of selecting hammer throw talents. Staerck (2003) found the toe-turn test(performing three consecutive toe turns about the longitudinal axis) as a good indicator for turning speed of the elite group of women hammer throwers compared with a non-elite group of female youth hammer throwers, as the elites achieved total turn time of 1.51s for three conventional heel-toe turn.

Bingisser and Jensen (2011) suggested that the leg should not be too active while the hammer comes around. The left side of the body is equally important during acceleration phase, but the left shoulder should not be pulled back, thus the radius will be reduced. The thrower and the hammer head should be accelerated together as a single unit. That means the velocity of both should to be the same, but regarding to the difference between the two masses, the kinetic energy would not be the same or equal.

Maheras (2009) does not attribute the increase to a horizontal pull-push mechanism of the feet against the ground, because such of movement stop happening after winds. Moreover, neither the increase of vertical velocity nor the shortening of the hammer ball radius are favored by being in DS. That is why the achievement of a long DS during the turns may not be as important as many think. Briefly, the increase in the velocity of the hammer head during the turns is due mainly to the addition of vertical velocity, and impart also to the shortening of the hammer radius.

Fujii et al. (2007) and Fujii and Ae (2008) reported that the decrease and increase in the radius of curvature, regardless of the magnitude of pulling force, had no relationship with the change in the hammer head velocity while the pulling force was oriented toward the instantaneous center of rotation (Figure 4). But it has relation with the leading angle (Figure 5), when it is 5° the velocity increases and decreased when the angle is -5°.The leading distance of the Handle, which is defined as the displacement from the handle to the connecting line between the hammer head and instantaneous center of rotation, has a positive effect on hammer head velocity. When it is positive, regarding to figure (6), in the duration between shortly before the high points (HPs) and the low points (LPs) the hammer head velocity increases and vice versa. That refers to the probability also of having HHKE increment in this phase in between the HPs and LPs because of leading hammer head.

At the low points no more twist between the hip and shoulder axis occurs, but there is a "tracking angle", the hip and shoulder axis are almost parallel. This shows that the legs are the effective "engine" for driving the implement through the low points of its trajectory. Often both female and male athletes finish the acceleration phases before the low point, in which case two acceleration phases can be noted (Hildebrand and Bartonietz, 1995). An angle between the hammerhead, grip and middle of the shoulder axis of <180° points to acceleration (e.g. of 168°, 1st turn the "tracking angle" is determined by 180°-168°= 12°).

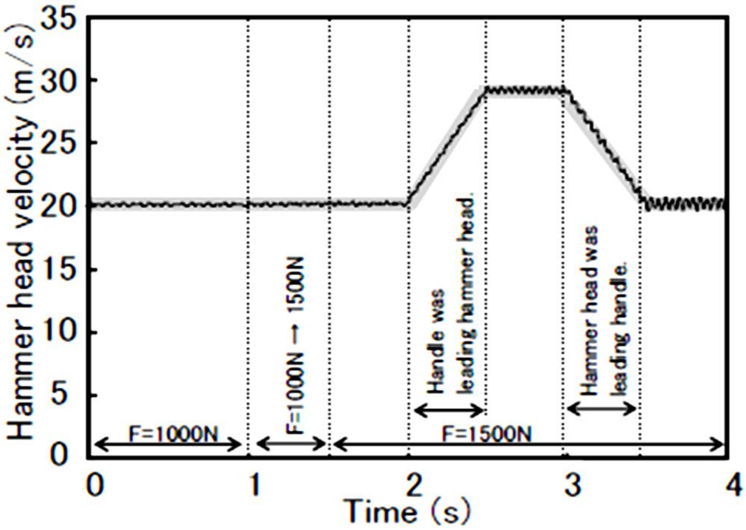



Figure 4.Examining the effect of leading angle on the hammer head velocity with simulation (Fujii and Ae 2008)

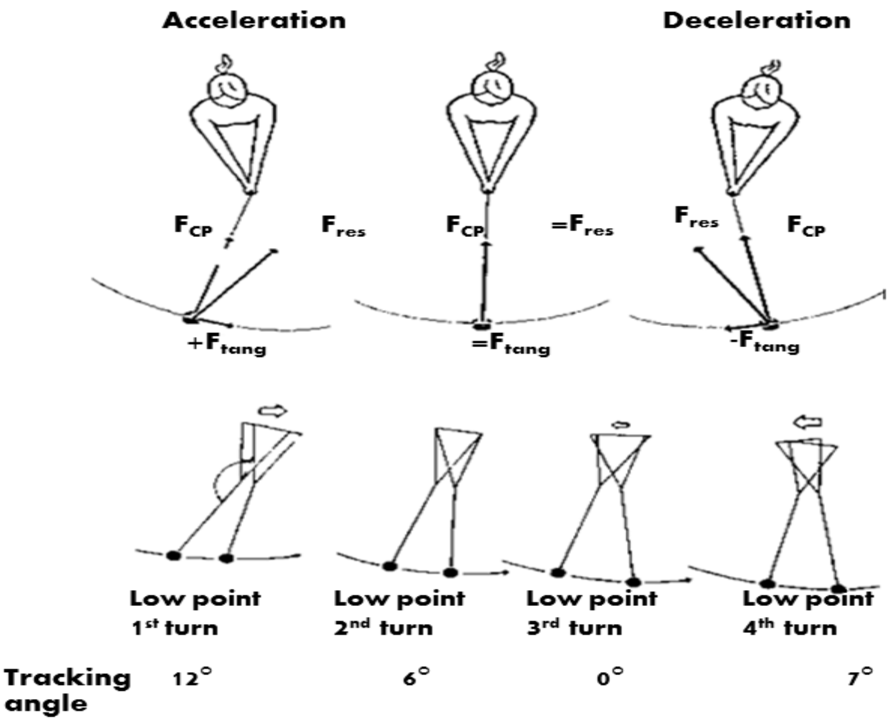



Figure 5. Sketch of the angle of leading hammer, the arrows above the shoulder axis snow the direction of movement of the shoulder girdle (Bartonietz et al.1995)

Susanke et al. (1986) suggest two positive factors to increase the hammer head velocity, first an obtuse angle, greater than 110° between the shoulder and hammer-wire axis, second the highest possible position of the implement ranging from 1.60 to 2.00 meters at the start of the delivery phase.

Cook (2006) recommended to develop muscular core strength and stability to enable the athlete to transfer energy from the ground (developed by his or her leg work) with higher efficiency (less amount of energy dissipation inside the body due to a stiffer muscular body core) to the hammer. The more efficient the body is at conducting that force at the point of impact (minimizing absorption), the faster an object will propelled through space and time. The desired power for throwing the hammer relates strongly to lower body power. Thus, lower body power would be a better predictor of current performance.

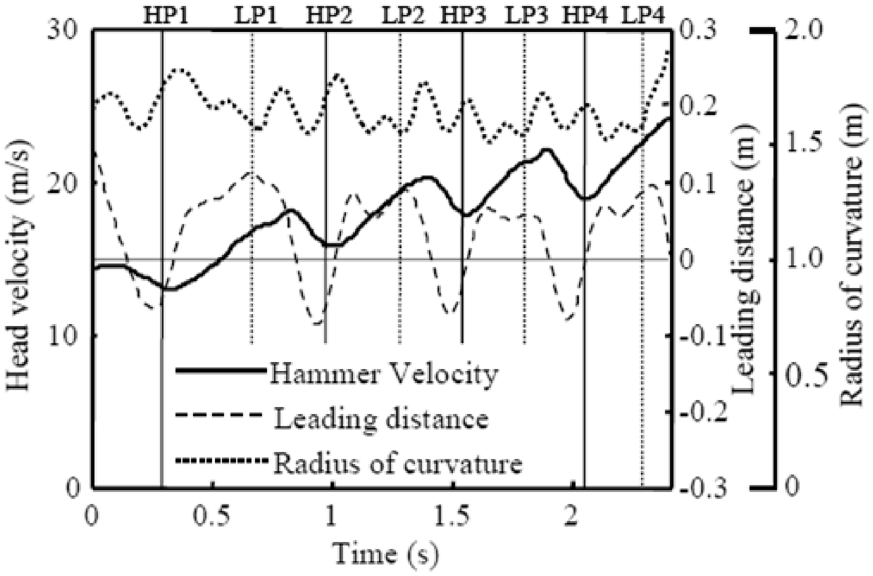



Figure 6. Hammer head velocity, leading distance of handle, and radius of curvature (Fujii et al. 2007)

### 2.5.2 Mass

Terzis et al. (2010) indicate that hammer throwers have larger lean body mass and larger muscular areas occupied by type II fibers[2], compared with relatively untrained subjects. Moreover, it seems that the enlarged muscle mass of the hammer throwers contributes significantly to the hammer throwing performance. Singh (2011) refers that a requirement to get the medal in the competitions like Olympic, Asian and Commonwealth Games, men and women athletes must have 55 to 60% and 50 to 55% of muscle mass, respectively. She reported, quoting Ecker (1974), that in hammer throwing, body

[2]These fibers, also called fast twitch or fast oxidative fibres, contain very large amounts of myoglobin, very many mitochondria and very many blood capillaries. Type II A fibres are red, have a very high capacity for generating ATP by oxidative metabolic processes, split ATP at a very rapid rate, have a fast contraction velocity and are resistant to fatigue. Such fibres are infrequently found in humans (http//www.brianmac.co.uk/muscle.htm) .

mass and strength (particularly the legs, trunk and arms) are the most important contributors to increasing the speed of the hammer at release. That refers to the role of BSKE like leg, torso and arms to increase the HHKE.

Okamoto et al. (2006) and Okamoto et al. (2008) considered the hammer throwing motion as two-body problem in the physics, between a thrower's body and a hammer head. That is because the body and hammer head rotate each other around the common center of mass of these two bodies. They confirmed by search that the thrower with smaller body weight has a disadvantage from the mechanical viewpoints, as well as muscle volume. Table (4) shows that the body weight of subject B was larger than that of subject A about 24%. Then radius of rotation, from the common center of gravity to hammer head in subject B, was longer than in subject A. However, the velocity of the hammer head at release were almost the same in two throwers, subject A's pulling force was larger than subject B's one because the centrifugal force (= the pulling force) was inversely proportional to the radius of rotation. The maximum pulling force increases by the throwing distance and decreases by athlete's body weight. The following predicting equation was resulted from the relation between the three parameters (MPF Maximum pulling force, TD Throwing Distance, BW Body Weight).

$$MPF(kgw)=(4.916x\ TD)-(1.087x\ BW)+49.6$$

Table 4.Release parameter and maximum force and body weight (Okamoto et al. 2006)

| Subject | Result (m) | Initial Velocity (m/s) | Release angle (deg) | Release Height (m) | Max. Pull Force (kgw) | Max. Pull Force/Weight (kgw/kg) | Weight (kg) |
|---|---|---|---|---|---|---|---|
| A | 76.37 | 28.4 | 40.0 | 1.46 | 324 | 3.60 | 90 |
| B | 76.67 | 28.9 | 38.3 | 1.84 | 307 | 2.74 | 112 |

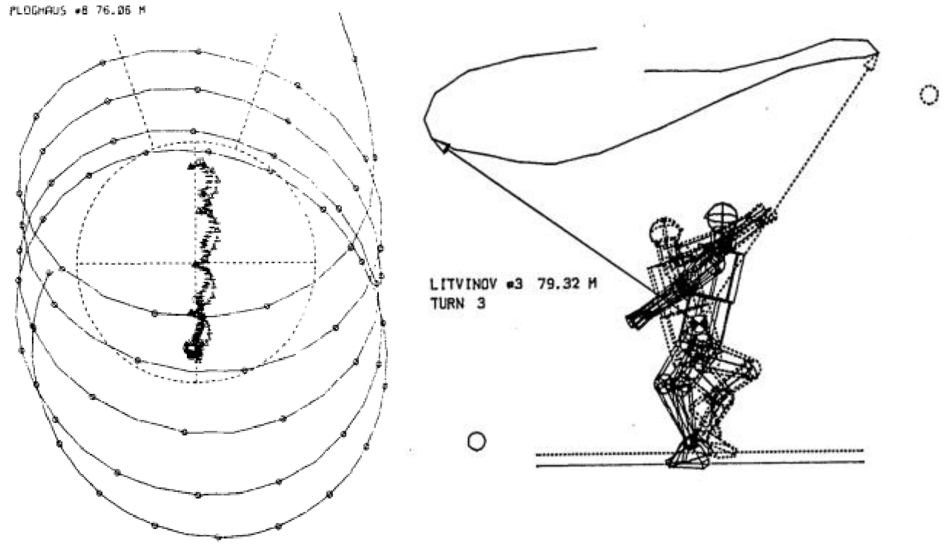



Figure 7. Overhead views of the paths of the hammer head, thrower center of mass and system center of mass. The symbols indicate instants separated by 0.04s intervals, on the right is for 76.05m throw, and on the left is for 79.32 m throw (Dapena, 1987)

Hammer throw technique essentially depends on rotation to accelerate the hammer head, where the thrower center of mass and the hammer center of mass are rotating about each other having a vertical axis of rotation. The masses of the body segments, as well the hammer, disrepute along this axis. The translational movement through the throwing circle, which results, in collaborates with centrifugal force in low and high point, in the coin shape of the rotation and make the axis of rotation itself rotates to form this coin in figure (7). Nevertheless, the orbit of hammerhead during the hammer throw is a curvature radius of the orbit, and they are not the same in every position of the performance. Athletes have to increase the hammer velocity gradually by alternately shortening and lengthening the distance between the hammerhead and centroid of its orbit (Dapena and Feltner, 1989).

## 2.6 Effective factors on kinetic energy of throwing hammer at release

Silverter (2003) indicates to the throwers would have a clear view of the essence of throwing , when they starts of view themselves as human beings developing as much kinetic energy as possible problem of controlling that energy and concentrating it into the hammer at release. The author considers the moments before the hammer leaves the hand and the fingers are crucial moments. He describes the successful throwing technique as a movement with:

1. High level produced kinetic energy by both of athlete and implement.
2. Enhancement of the range of motion and release velocity by a significant stretching and elastic tissue
3. Effectively transfer of significant kinetic energy from the body to the hammer just before release.

The equation of estimating throwing distance includes three main parameters at the moment of release, which are height, angle and velocity of release ignoring air resistance.

$$Distance = \frac{v^2}{g}\cos\theta\ \left(\sin\theta + \sqrt{sin^2\theta + \frac{2gh}{v^2}}\right) \text{ (Otto, 1994)}$$

In practice, release velocity is the most important factor as far as improvement potential is concerned. It is one of the factors, which should be maximized by the athlete's actions; figure (8) shows the linear relationship between the distance and the velocity of release. Female athletes achieve angles of release of between 29° and 42°, while a difference of 5° in the angle of release corresponds to a reduction in the distance thrown of approximately 1 m (Bartonietz 1997). The GDR Hammer Throw record (82.64m) was achieved with a release velocity of 29.3m/sec, and an angle of release of 38°. The higher release angle would have a negative influence on release velocity (Bartonietz, 2000; Bartlet, 2007).

The velocity of release as an indicator of the hammer's kinetic energy could be maximized by the athlete's action (Bartonietz, 2000). The method of achievement a maximum release velocity only if the hammer imparted a maximum tangential acceleration impulse, for example an 85m throw, this acceleration impulse is 210Ns. This can be achieved by making the acceleration path as long as possible. So it must be achieved an optimum relationship between the radius of the hammer path and the angular velocity (Bartonietz et al, 1988).

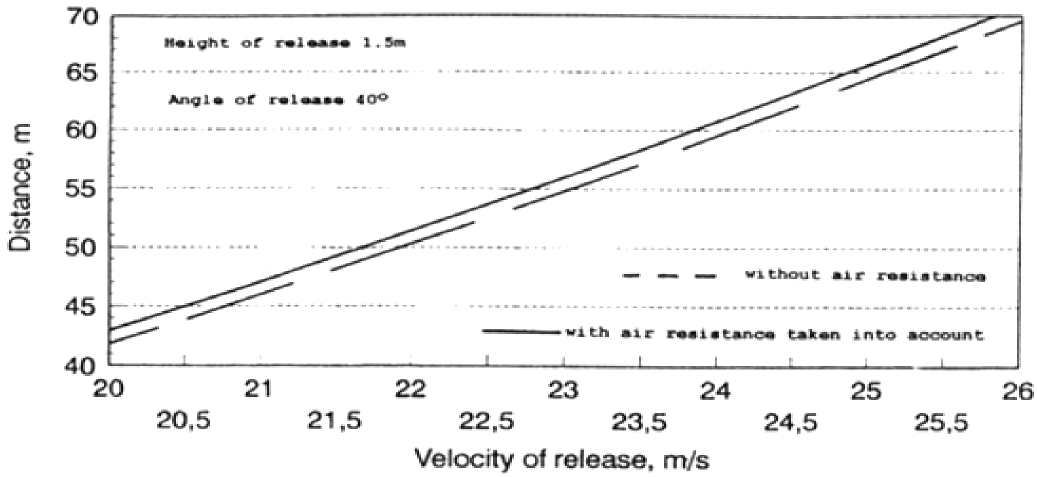



Figure 8.Relationship between velocity of release and the distance thrown in the women's hammer throw (Bartonietz, 1997)

***Angle of release*** The motion analysis for the all trials of hammer throw in 2002 USATF (United States Track and Field) indicates that there is no optimal angle of release for hammer throw but the average for Women is 36.9° , and steeper angle probably causes that the hammer head hits the ground. This would mean that taller thrower may be able to handle a greater release angle, but the trend of increase toward 45° results in an inverse relationship with the release velocity (Hunter and Killgore, 2002).

Konz (2006) reported that the average release velocities for female hammer throwers at USA Track and Field National Championship 2003 (USATF) in California and at the IAAF world athletic finals 2003, was 27.5 m/s, mean height of release was 1.41m, and the angle was 41.8º. She added also that the taller thrower will allow the implement to travel further than the shorter Female.

***Height of release*** The hammer should leave the hands at the end of the delivery at shoulder level, which depends on the thrower's anthropometry and technique (Bartonietz et al.,1997; Gutiérrez, 2002). The height at release of the implement affects the total amount of time it is in the air. The higher the release point is, the longer the implement in the air is (Hay, 1993; Kreighbaum and Barthels,1996; Knudson, 2003).

## 2.7 Kinetic energy transfer

Bartonietz (2000) indicates to the energy transfer as the main principle in both training and competition performance diagnosis. This has to be considered by selecting training exercises and by planning the training load. Understanding the interaction between the links in the limb chain, which based only on kinematic data, is limited. A kinetic-based approach to throwing movements throwing in particular provides deeper insights into the movement structure.

Silvester (2003) considers it is a challenge to thrower to move his body and the hammer with a high velocity, possessing a great KE, in the throwing area as a way to enable a large portion of developed KE as possible to be transferred into the hammer at targeted angle and height at release.

### 2.7.1 Segmental sequence of transferring KE to the implement

Knudson (2007) refers that the overarm throwing such baseball, a sequential action of the completely kinematic chain is use, beginning with the legs, followed by trunk and arm motions. That means a range of motion from the entire body to transfer energy from the ground to the implement. The Coordination Continuum Principle suggests that movements requiring the generation of high forces tend to utilize simultaneous segmental movements, while lower-force and high-speed movements are more effective with more sequential movement coordination.

Bartonietz (1996) indicates that the release velocity of the given mass of an implement represents the energy that is receives from the thrower to the hammer. To reach a greater range the athlete must be able to realize the required high level of power for more kinetic energy in a shorter time interval to the segments of the body and to the implement. It would be clear how a larger amount of energy is transferred in a shorter time is created, when we make a comparison between a young hammer thrower with a 5kg implement turns slower than Sedych in his 86m throws and has a release velocity that is about 5 m/s slower. With increasing, hammer masses (from 5kg to 7.26kg), the athlete needs large amounts of energy to be transferred to the implement in shorter time intervals.

Goff (2009) reports that Discus throw movements are designed to release maximal stored energy into the discus from thrower own kinetic energy. The path of the right shoulder, its position, and the relation between the shoulder axis and the throwing arm are important for the transfer of energy to the discus. At swings, the right arm is far behind him so that the discus nearly faces the throwing direction. The muscles and tendons in the powerful right arm are stretched, thus storing strain potential energy. As he turns, he drops his center of mass by bending his knees. Some gravitational potential energy is consequently transferred into stored energy in his stretched leg muscles. During the turn, the center of mass is being moved toward the front of the circle simultaneously. The final full turn allows him to release a good fraction of the energy stored in the stretched muscles by accelerating the arm forward and the legs straighten out.

Bartonietz (2000) indicates that the energy transfer between thrower and hammer is relevant for performance diagnosis and training, and needs more research. Effective throwing involves accelerating the hammer by reducing the moment of inertia of the thrower. With a perfect throwing pattern, the additional increase of the angular momentum reinforces the velocity outcome. Therefore, the coach has to enhance the familiarization with the energy transfer between athletes and implement redistribution of rotational energy. The effective training implements for each athlete have to be selected taking into account at least the duration of the turns and the velocity of release, respectively, distance thrown. A rough estimation shows that for a 10% increase in distance thrown, the available average power must increase by 20%. As performance improves during the training years, athletes must apply a greater amount of kinetic energy to the implement (higher release velocities and greater mass) in shorter time intervals (i.e. faster turns).

### 2.7.2 Sequence of energy transfer among segments

Zatsiorsky (2002) refers to the energy transfer between adjacent and nonadjacent segment. The joint torques can transfer the energy between the adjacent segments while the total energy of human body us conserved, but it depends on the direction of rotation, the difference between the angular velocity and the change in the joint angle. On the other hand, when muscles cross two joints , or a segment, energy may be transferred between the nonadjacent segments to which a two-joint muscle is attached rotate in the same direction. During takeoff, the monoarticular hip extensor muscles contract and the hip extension occurs. If the two-joint rectus femurs act isometrically, it transfers the mechanical energy generated by the hip extensors from the hip to the knee joint.

The kinetic chain is based on the “kinetic link principle” where the generation of high end point velocity accomplishes with the use of acceleration and deceleration of adjoining links. That is , the segments reaches its maximum of speed consecutively beginning for those farthest of the kinetic chain free end (López de Subijana and Navarro, 2009).

Zajac et al. (2002) refer that redistributing energy among segments is the primary function of the muscle rather than producing or dissipating energy. Muscle force can cause significant segmental energy redistribution irrespective of whether the muscle produces mechanical work output by shortening (acting concentrically), dissipates energy by lengthening (acting eccentrically), or neither by staying at a constant length (acting isometrically), but the ability of a muscle to redistribute segmental energy seems to be less appreciated.

During the initial period of ground contact during running, braking causes decrease of the body’s energy and the center of mass is lowered by hip and knee flexion. Some of this energy can be stored in the tissues of the lower limbs elastic potential energy. Later, during the drive-off phase this energy can be returned to contribute in increasing the height and velocity of the center of mass. To reduce the total energetic cost of running two mechanisms are used :1) the storage and later return of elastic potential energy by the stretch of elastic structures, and 2) the passive transfer of energy from one body segment to another (Grimshaw et al., 2006; Jenkins, 2005).

While the throw can be characterized by the progressive contribution of the body segments to the momentum of the object to be projected (with a constant mass, the change in momentum corresponds to a change in velocity), the task can be accomplished with a variety of motion. These different forms include the push throw (e.g., shot put) or pull throw (e.g., hammer throw). Because the throws involve multiple body segments, an interaction torque is an effect that one segment exerts on its neighbors due to its motion. The magnitude of an interaction can be much greater than that of a net muscle torque, for example the skilled baseball players are able to exploit the interaction torques to increase the speed at which a ball can be thrown. These players achieve this effect by increasing the torque exerted by shoulder and trunk muscles, but not the muscles that cross the elbow or wrist (Enoka, 2008).

In Golf sport, Shoulder ex/ext, ulna deviation and elbow extension do not make a significant contribution to release speed. They may, however, be important to ensuring that the release of the object is optimal in terms of angle, orientation, or spin. For example, modern players are taught to “lead with hips” so they can generate large amounts of rotational torque which is transferred to the club head and consequently to golf ball velocity. However, this technique is one that can potentially lead to lower back problems (Grimshaw et al., 2006).

Kenny et al. (2008) studied the segmental sequencing of the transfer of KE by means of computer simulation. They indicate to the equivalent trunk and arms linear velocity, which is showed by the high level of correlation between driver and iron peak KE and timing of peak KE relative to impact, and the highly significant differences between KE output for body segments for two kinds of clubs. In addition, peak KE magnitudes increased sequentially from proximal to distal segments during swing simulations for both the driver and iron. But timing of peak KE was not sequential from proximal to distal segments, nor did segments peak simultaneously. Rather, arms peaked first, followed by hips, torso and club. This gives indication to the subjective optimal coordination of sequencing.

Cook (2006) suggests that developing strength and power in the upper and lower body as well as the core, force can be transmitted from the ground to the hammer. The development of power allows the thrower to apply force into the ground thereby transferring it into the hammer to generate power. If the body is the conduit through which force is conducted at the point of impact, then the more efficient the body is at conducting that force (minimizing absorption), the faster an object will be propelled through space and time The desired power for throwing the hammer relates strongly to lower body power.

### 2.7.3 Statistical analysis for finding the best set of BSKE

Regression analysis is a statistical tool for the investigation and understanding of relationships between variables (Zou et al., 2003). Two kindes of regression analysis were used in this study the linear and stepwise. Multiple regression analysis is a statistical tool for understanding the relationship between two or more variables (Rawlings et al., 1998). Here are two general guidelines for selecting explanatory variables: **First**, include enough of them to make the model useful for theoretical purposes and to obtain good predictive power. **Second**, as a counter balance to the first goal, keep the model simple. To avoid multi-collinearity, it is helpful for the explanatory variables to be correlated with the response variable but not highly correlated among themselves (Agresti, 2007).

#### *2.7.3.1 Uses of the Regression Equation*

Rawlings et al. (1989) mentioned the purpose of the least squares analysis, how the regression equation is to be used and will influence the manner in which the model is constructed.

1. providing a good description of the behavior of the response variable;
2. prediction of future responses and estimation of mean responses;
3. extrapolation, or prediction of responses outside the range of the data;
4. estimation of parameters;
5. control of a process by varying levels of input; and
6. developing realistic models of the process.

#### *2.7.3.2 Finding Best Subsets and Model Selection Procedures*

More recently, attention has focused on identifying the best subsets within each subset size without computing all possible subsets. Most software contains automated variable selection procedures that scan the explanatory variables to choose a subset for the model. These routines construct a model by sequentially entering or removing variables, one at a time according to some criterion. Among the most popular automated variable selection methods are backward elimination, forward selection, and stepwise regression (Agresti, 2007).

***Backward Elimination*** begins by placing all of the predictors under consideration in the model. It deletes one at a time until reaching a point where the remaining variables all make significant partial contributions to predicting y. For most software, the variable deleted at each stage is the one that is the least significant, having the largest P-value in the significance test for its effect (Agresti, 2007).

***Forward selection*** adds one variable at a time to the model until reaching a point where no remaining variable not yet in the model makes a significant partial contribution to predicting y. At each step, the variable added is the one that is most significant, having the smallest P-value. For quantitative predictors, this is the variable having the largest t test statistic, or equivalently the one providing the greatest increase in $R^2$ (Agresti, 2007).

***Stepwise regression*** is a modification of forward selection that drops variables from the model if they lose their significance as other variables are added. The approach is the same as forward selection except that at each step, after entering the new variable, the procedure drops from the model any variables that no longer make significant partial contributions. A variable entered into the model at some stage may eventually be eliminated because of its overlap with variables entered at later stages (Agresti, 2007).

## 2.8 Conservation and dissipation of the energy

### 2.8.1 Conservation of mechanical energy

The total mechanical energy of a rigid body is equal to the sum of its kinetic energy and gravitational potential energy, when the total mechanical energy of the system remains constant, energy is conserved, and the system is said to be conservative. In the real world, no system is completely conservative; some energy is always lost by virtue of the system's interaction with the environment (Abernethy, 2005).

A common mistake that is made is to assume that conservation of energy applies only to kinetic and potential energy—that the sum of kinetic and potential energy for a given system is constant. This statement is only true if there are no other energy modes (thermal, chemical, etc.) that are available. If there is some other way that energy can be stored, into thermal energy for instance, then the sum of kinetic and potential energy may not be constant, in other words, The overall energy of the system is still conserved, but the sum of the potential and kinetic energy is not (Palmer, 2005).

The conservation of mechanical energy refers to the specific form of the law of conservation of energy, which is of value in sport and exercise science as it uses only mechanical forms of energy. It refers to exchanges between just two types of energy the gravitational potential energy, and linear and angular kinetic energy. In general, the conservation of mechanical energy applies to projectile flight where air resistance can be neglected. It cannot be applied where there are obvious energy losses due to friction or other resistances. The muscle is essentially a device, which converts chemical to mechanical energy. When energy changes from chemical to mechanical a certain amount of heat is given off (Grimshaw et al., 2006).

We know how to explain Katarina Witt's (ski dancer) fast spins. What is happening with energy during that time when her spin rate increases? You may have heard of *energy conservation* before. The idea behind that powerful conservation law is that the total energy in a closed system remains constant in time. The "closed system" concept is omnipresent in physics. We apply energy conservation to systems that cannot exchange energy with their external environments. If Katarina Witt shoves off the ice and does nothing else while gliding on the ice, she will eventually come to rest, because she loses her energy of motion, owing to the frictional interactions between her skates and the ice and between the air and her body. If our model system consists of only Katarina Witt, total energy is not conserved, since energy leaks out of the model system. If, by contrast, our model system is made up of Witt and her surroundings, specifically the ice and the air, total energy is conserved (Goff, 2009).

### 2.8.2 Energy dissipate

It is important to recognize that the primary function of a muscle can be to simply redistribute energy among segments rather than produce or dissipate energy. The redistribution of segmental energy results because the force generated by a muscle creates simultaneous segment accelerations and decelerations throughout the body. Muscle force can cause significant segmental energy redistribution irrespective of whether the muscle produces mechanical work output by shortening (acting concentrically), dissipates energy by lengthening (acting eccentrically), or neither by staying at a constant length (acting isometrically). Through the importance of energy production and dissipation by muscles to task execution has been emphasized, the ability of a muscle to redistribute segmental energy seems to be less appreciated (Zajac et al., 2002).

The mechanical energy the muscles produce for human movement can flow along one of three main paths (Figure 9). The first is a conservative path where the energy can be stored in a piece of equipment and reutilized by the athlete. The second is a non-conservative path where the energy is dissipated as heat, sound, vibration, etc. The final is the application of energy directly to performance to move the athlete or equipment (Hong et al., 2008).

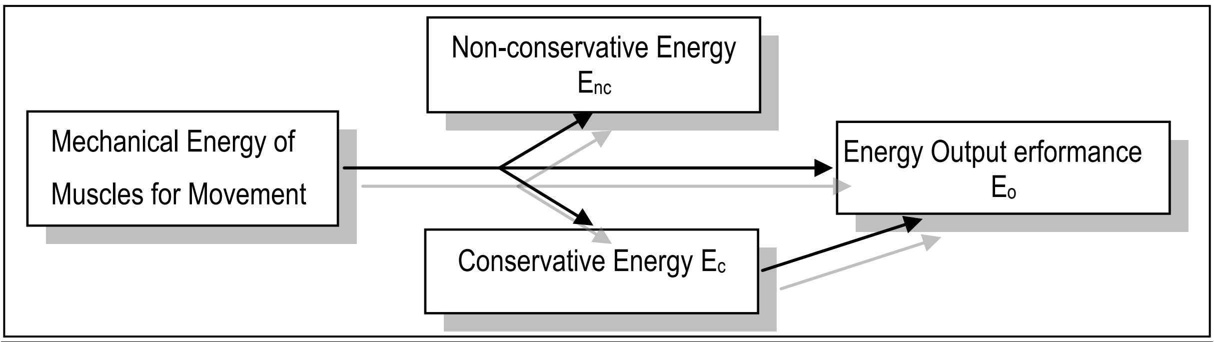



Figure 9. Paths of mechanical energy flow from the muscles for sport performance
(Bartlett et al. 2008 adapted from Van Schenau and Cavanagh 1990)

Grimshaw et al. (2006) report that object sometimes let energy to be dissipated in order to stop (i.e., the linear kinetic energy needs to be reduced to zero). For example, braking forward motion by extending out a leg; stretching out for catching a ball then absorbing the ball into the body. These actions are designed to reduce energy in a controlled manner. Muscular chemical energy is required to both increase and reduce the kinetic energy. Thus, movements that involve a lot of starting and stopping (like games play or racket sports, for example) also require high levels of chemical energy expenditure. Equation 2 also indicates that linear kinetic energy is related to body mass and so in these examples the heavier person will have a more dif cult job to stop. Heavier people are generally considered less agile.

Galileo found that objects with a very low air resistance continued to move almost indefinitely when on almost-frictionless surfaces. He realized that if the objects could move in conditions where there was no air resistance or friction, they would never stop! (Blazevich, 2007)

The aerodynamic characteristics of the projectile can significantly influence its trajectory but differently. The projectile may travel a greater or lesser distance than it would have done if projected in a vacuum (Bartlett, 2007). For the Hammer, air resistance is a factor that reduces the throw distance about 2% (Bartonietz et al., 1988; Bartonietz, 2000; Mizera and Horvath, 2002; Dapena et al., 2003; and Gutiérrez, 2004). For a throw of 70m with the men's implement, air resistance will reduce the distance thrown by approximately 1.5m. The women's implement has a surface area, which is 75% of that of the men's implement. Therefore, we can estimate that air resistance may reduce the distance of a throw in the women's event by approximately 1m (windless conditions) (Bartonietz et al., 1997).

Mizera and Horvath (2002) detected the non-linearity relationship (Figure 10). Air drag has a considerable effect on hammer throw ranges, while in a vacuum, the world records of hammer throw (L=86.74m) would be 88.09 m ($\Delta$L=135 cm), which would mean an enhancement of 2.8%. A relatively small wind velocity of 2m/s parallel to the release direction results in a change of the hammer throw range of about 66 cm (head wind) and 62 cm (tail wind). This drag force depends on the projected area of the men hammer ($A_h$=0.0138 m$^2$) and the drag coefficient average ($K_h$=0.70) because the movement of the handle and the wire erratically around the head during the flight leads to a variation in the drag force along the trajectory, as well the square of the relative wind velocity vector.

Mizera and Horvath (2002) reported also that the average air pressure decreases approximately exponentially with altitude. The exact change of air pressure depends strongly on the meteorological conditions; nevertheless, the relative change of air pressure can reach about 30% at altitudes of several thousand of meters. The decrease of air pressure results in a decrease in air density; which decreases the air drag, the consequence of which is an increase in distance. Air pressure varies about 2 kPa among cities at similar altitudes. A 72 kPa pressure change would have an effect in the order of 16 cm on hammer range. Air pressure has an important effect on range only when it varies by a large amount, but this occurs only when the two cities are at very different altitudes.

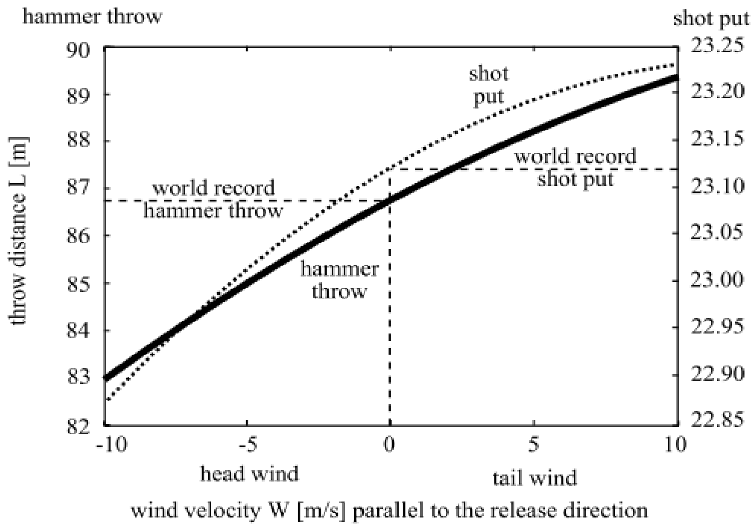



Figure 10. Male world-record hammer throw distance L as a function of wind velocity W parallel to the release directionfor Athens' latitude (Mizera and Horvath 2002)

Blazevich (2007) indicates to surfaces with lower friction are usually safer than surfaces with high friction. Understanding of friction could be used to improve performance in many sports, as to try to optimize the friction between shoes and court surfaces to improve performance and reduce injury risk. As well as to minimize friction between clothing and skin, to prevent abrasion.

## 2.9 Relative studies to hammer throw biomechanics

As throwing hammer technique is complex, and still need efforts to be enhanced by athletes. In addition, women still have a lot to achieve in this competition. There is still the attitude to study the biomechanical characteristics of the top athletes and their performance and reexamine the kinematics repeatedly using more equipment that is technical and the technological progress. In the next section, the publications about hammer throw biomechanics would be illustrated.

Dapena (1986) studied the motions kinematics of Center of mass for each of thrower, hammer and Thrower-hammer system in the hammer throw. The participants were 8 highly–skilled hammer thrower including the present World Record holder and his predecessor. They were filmed with 2 high-speed motion-picture cameras. The study found that the system's center of mass followed a roughly trochoid pattern in approximate synchrony with either the hammer, or an essentially straight trajectory.

Susanka et al. (1986) studied the hammer-athlete relationship during the hammer throw. They filmed the hammer throwers in the first World Championships in Athletics held in Helsinki in 1983, and other international competitions. They used two phase-locked Photo-Sonics Biomechanics 500 cameras at 200 frames per second, which were placed 15.00 m behind and 21.00 m to the right side of the throwers with both camera lens axis horizontal and intersecting in the centre of the throwing circle 1.80 m above the surface of the circle and at 90.0 degrees to each other. They illustrated in the result the main factors to increase hammer head velocity. They suggested that the path of the hammer head during the throw should take the longest path possible, the vertical lift should increase gradually, and acceleration of hammer must occur before the DS while the hammer is descending.

Dapena and Feltner (1989) studied the influence of the direction of the cable force and of the radius of the hammer path on speed fluctuations during hammer throwing. They found that neither the gravity nor to the forward motion is produced mainly by pulling alternately ahead and behind the position of the centroid of the hammer path are the reason of the portion of hammer speed fluctuation, as well as not by the alternation increase and decrease in radius of hammer path. It was also found that a general shortening of the radius of the hammer path contributed to the total increase in the speed of the hammer between the start of the turns and the release.

Dapena and McDonald (1989) analyzed the angular momentum of the hammer throw by studying the path of the angular momentum vectors, forward-backward tilt of the trunk as well and the height of the hammer plane relative to the system center of mass as well. The result indicated that the paths of the angular momentum vectors, the trunk tilt, and the height of the hammer plane relative to the system center of mass were interrelated. Two theories were proposed to explain why the athletes who had forward trunk tilt in the early turns tilted backward in the final part of the throw.

Karalis (1991) used experimental data for the center of mass paths of the hammer and the thrower to study the body main control driving torques at the various points in the movement pattern. The result refers that the component x of control torque of centre of mass is acting in the pelvic plane and always positive. The y component is acting in the pelvic transverse plane and its activate corresponds to a succession of positive and negative torques during the SS. The negative torqueses during the DS are greater than the positive ones which mean that the muscles that rotate the trunk backwards should have a greater mechanical activity. The positive torques, which that activate the trunk forward at any left heel strike are immediately succeeded by a negative torque which becomes maximum during the DS. When the stretching resistance of the body has a peak value (negative torque value) the body rotates (with a left heel strike activity) giving rise to a positive torque and so on. Accordingly, the energy fed into each step of an active process would be used to overcome the passive process. The legs' forces with the constraint that the magnitude of the inertia forces applied to the centre of mass do not exceed the total weight of the hammer and the thrower. In fact, if the inertia forces exceed the total weight of the system (thrower and implement weight), the thrower would need to pull up on the ground (impossible) to accelerate the hammer downwards.

Maronski (1991) examined the possibility of hammer and discus throwing technique improvement by the optimal implement distance from the axis of rotation. For Hammer throw, the acceleration of the competitor-hammer system should take place with the hammer at the maximal distance from the axis of rotation. At the end of the final turn the maximal shortening of the radius should be done.

Bartonietz et al. (1997) studied characteristics of top performances in the women's hammer throw Basics and technique of the world's best athletes who is Olga Kuzenkova the leading female hammer thrower in 1996. They reported that The main requirements for the men's hammer throw are also valid for the training structure of female athletes i.e. an increase of the training quality, and the optimisation of the effects of the yearly training cycle, by varying the components of the training load with regard to volume and intensity.

Lee et al. (2000) compared the curvature radius of different performance (63.20m and 68.46m) of hammer throw. The results indicated that the patterns were completely different, which is probably caused by the changes of posture when athletes turn the whole body with the hammerhead and the better trial generated more concentric acceleration.

Mizera and Horvath (2002) compared the influence of Earth rotation on the range of the male hammer throw and shot put with that of air resistance, wind, air pressure and temperature, altitude and ground obliquity. They reported that the normal variations of certain environmental factors can be substantially larger than the smallest increases in the world records as acknowledged by the International Amateur Athletic Federation and, therefore, perhaps these should be accounted for in a normalization and adjustment of the world records to some reference conditions.

Gutierrezet et al. (2002) studied the temporal factors during SS and DS, the radius of the turn, speed and the angular momentum of the hammer head, azimuthal angles, the tangential velocity of the hammer for the men and women finalist of hammer throw event at the World Championships, Seville1999. The result indicated that there are no differences between women and men in such matters as azimuthal angles and radius of the turn. Also they stated that the only clear difference found was the time taken for each gyration. The final phase has importance for the distance of the throw and especially the increase produced in the resultant angular momentum.

Dapena et al. (2003) wanted to determine how much the predicted distance of a hammer throw is affected by (1) ignoring air resistance and (2) assuming that the centre of mass of the hammer coincides with the centre of the ball. Three-dimensional data from actual throws (men 72.82 +/- 7.43 m; women 67.78 +/- 4.02 m) were used to calculate the kinematic conditions of the hammer at release. A mathematical model of the hammer was then used to simulate the three-dimensional airborne motion of the hammer and to predict the distance of the throw. The distance predicted for vacuum conditions and using the ball centre to represent the hammer centre of mass was 4.30 +/- 2.64m longer than the official distance of the throw for the men and 8.82 +/- 3.20 m longer for the women. Predictions using the true centre of mass of the hammer reduced the discrepancy to 2.39 +/- 2.58m for the men and 5.28 +/-

2.88m for the women. Predictions using air resistance and the true centre of mass of the hammer further reduced the discrepancy to -0.46 +/- 2.63m for the men and 1.16 +/- 2.31m for the women. Approximately half the loss of distance produced by air resistance was due to forces made on the ball and the remainder to forces made on the cable and handle.

Rojas and Gutiérrez (2004) studied the effect of aerodynamic resistance on the scope release of male and female hammer elite throwers. They give three conclusions first the vector speed of the hammer must be calculated according to the speed of its center of masses and not of the ball of the hammer. Second the main difference between the throwing of men and women is in the release velocity are (28.7m/s and 26.9m/s) and no significant differences in the height and angle of release. Third is that the aerodynamic resistance is greater in men's than in women's because of the hammer head diameter. And less affected by its scope with 13% for women and 9% of men than the theoretical due to greater mass of men's hammer than women's.

Hunter (2005) targeted in this study to calculate the venue-induced effects of gravity and air resistance on the flight of a hammer. A computer simulation combined with measurements from the 2002 USATF championships predicted a throw distance with an equal release velocity and angle at various venues, including Los Angeles, CA; Provo, UT; Gunnison, CO; Oslo, Norway; and Mexico City, Mexico. A 3D analysis tracking the hammer head at release provided average initial heights, speeds, and angles of the furthest throws by the top 9 men and top 9 women at the 2002 USATF Championships. The simulation showed that throwers who use angles close to 45° would have a slightly greater benefit at altitude than others, due to longer flight times, although less steep throws typically go faster, creating a complex situation for determining appropriate conversions. This study found that temperature has only a small effect on the distances of hammer throws. Altitude and latitude have a larger effect but not large, in fact, smaller than the effect of moderate winds.

Okamoto et al. (2006) studied the influence of body weight on hammer throw by calculating the initial conditions at release and maximum pulling force acting on hammer head during throwing of two elite throwers the release parameter were almost. The difference was in the throwers' body weight (24%). The thrower with smaller body weight had a disadvantage, from the mechanical viewpoints as well as muscle volume, because for the almost same parameters and a throwing distance the heavier thrower applied smaller pulling force value.

Konz (2006) compared between male and female hammer throwers of technique and performance level. She used the trials of top 16 male and female throwers at the 2003 WAC Finals and the top 13 male and female throwers from the 2003 USATF Nationals for her purpose. The results divided into two sections first the sex differences study which referred to many variables were significant between sexes. Several variables that predict success in hammer throwing distance were significant.

The anthropometric measurement of athlete mass contributes to greater throw distance. Release velocity predicted throwing distance radius.

Murofushi et al. (2007) studied the hammer acceleration due to thrower and hammer movement patterns. For this purpose they captured trials of three athletes with 3 high-speed cameras 250 f/s; two university athlete hammer throwers and the Asian record holder in hammer throwing, in addition 8 force plate form were used. The result was presented as a function of azimuth angle instead of time. The results indicated that for all athletes, the hammer head speed increased during the DS and decreased towards the HP of the SS. And the tensile force increased with each turn. In contrast, with the exception of the final release phase, the vertical ground reaction force did not change markedly. The peak of the wire tensile force almost coincided with the middle of the peaks between the right and the left foot force in each turn. There is difference between the athletes in the resultant forces for the left and right foot. It is conjectured that the repeated ground reaction force patterns of each turn involving the different use of the right and left foot and the vertical asynchrony patterns between the thrower's centre of mass and the hammer head are necessary for accelerating the hammer during turns.

Fujii et al. (2007) used trials by 10 Japanese male throwers (43.15 – 68.21m) reexamined the mechanism of acceleration during hammer throw by calculating the hammer acceleration and the leading distance of handle. In addition, the 2D computer simulation was carried out to test 3 hypotheses. The result stated that the handle with the positive leading distance had the effects on the increase of the hammer head velocity. On the other hand, the handle with the negative leading distance had the negative effects. The normal acceleration of the hammer head had no direct effects on the increase of the hammer head velocity.

Mercadante et al. (2007) presented the methodology that allows one to quantify the release variables of the throw and the curves of velocity in function of time, characterizing the throw in competition. The result of comparison between Brazilian and international throwers shows that the Brazilian throwers have difficulty in to reach better results due to low release velocities, when compared to the finalists of Seville 1999, and during the turns when compared to Yuriy Sedykh's throw.

Okamoto et al. (2008) investigated the influence of initial conditions at release on the throwing distance of hammer throw. The result shows that only a significant correlation was obtained between the initial velocity and the distance. The angle of projection strongly depends on the inclination of the orbital plane of hammer head just before the release and the release height which depends on the timing of the release of hammer head. In other words, athletes cannot choose the angle of projection and release height independently. And confirmed that the initial velocity of hammer head was the most dominant factor which affected the performance.

Judge et al. (2008) have attempted to bridge the gap between the researcher and the coach in teaching the hammer throw, by integrating biomechanical analysis. They employed the use of video analysis as an essential part of the coaching/teaching system. This USATF Women's development hammer project is an example in which the cooperation between sport science and coaching helped to produce an American record of 73.87m by Erin Gilreath in the women's hammer in 2005.

Gutiérrez (2009) studied the relation between angular displacements of the hammer in the DS and its velocity in the hammer throw. The results do not give any statistically significant values, which confirm the existence of a relation between the angular displacement of the hammer head and the change of velocity produced in the DS. Therefore, they were not with prolonging DS as a significant contributing factor in the result, except in the first turn when the tangential velocity of the hammer center of mass is relatively low. When the hammer reaches a certain velocity, its angular displacement in the DS tends to be less than those that achieved when the average velocity of the hammer is slower. However, as the tangential velocity of the CG increases, bringing the support excessively forward could produce a certain reduction of the angular velocity of the thrower and hammer system, and some momentum of force contrary to its angular displacement appears, so prejudicing the throw.

Ohta et al. (2010) analyzed the motions of the hammer to understand the mechanism of acceleration with a hula-hoop model using an energy pumping mechanism. The condition is expressed in terms of the tugging force time’s velocity to pump the hammer energy. As far as normal direction, tugging near the low point gives the optimal way to yield maximized restored energy in each turn, because the tensile force reaches a local maximum near the low point. This is an approach for restoring kinetic energy using parametric excitation, which is a principle to increase energy. Giving a tangential acceleration in phase with gravity using another type of parametric excitation yields a larger force near the LP and this maximizes this energy pumping effect.

Brice et al. (2011) investigated the relationship between the cable force and linear hammer speed in the hammer throw and to identify how the magnitude and direction of the cable force affects the fluctuations in linear hammer speed. Five male and five female throwers participated and were required to perform 10 throws each. A 21 infra-red camera system (Oxford Metrics, Oxford, UK) with frame rate of 250 Hz was used to record the positions of the reflective markers. The cameras were positioned at varying heights around the throwing circle. The test was completed after twilight conditions to avoid the reflection of sun infra-red. A strong correlation was observed between decreases in the linear hammer speed and decreases in the cable force (normalized for hammer weight). A strong correlation was also found to exist between the angle by which the cable force lags the radius of rotation at its maximum (when tangential force is at its most negative) and the size of the decreases in hammer speed. These findings indicate that the most effective way to minimize the effect of the negative tangential force is to reduce the size of the lag angle.

### 2.9.1 Comment on the relative studie

These studies were helpful to collect and differentiate among the methods of research according to targeted aim of study. At the same time it was like to stand where the other stopped to continue the science chain in this field.

two categories of the studies have been observed (kinematic and kinetic) in order to characterize hammer throw performance, which performed by top athletes nationally or internationally. The researchers used motion analysis programs after recording the throws, recording video technique varied according to the technology improvement starting with using the film through digital cameras reaching to the infra-red camera system.

The studies showed focusing on the hammer head kinematics and kinetics regarding to the thrower center of mass and system center of mass. Also, it worth mentioning that some studies reexamined the same parameters but for different performance levels.

It has been also observed that just Ohta et al. (2010) who started to pay attention to the energy of hammer motion. But no one, in the light of the collected studies, studied statistically and numerically the biomechanical parameters of body segments of the thrower. In addition the correlation between the kinetic energy output of the body segments and the output kinetic energy of the hammer head during performance phases. The new also in this current study is the novel use of liner and multi regression analysis to predict the output HHKE by BSKE and BKE values at release phase. In addition, studying, the segmental sequence of kinetic energy in every phase.

# 3 Literature Review of Measurement Information System

Interest in human motion goes back very far in human history, and is motivated by curiosity, needs or methods available at a time. The modeling, tracking, and understanding of human motion based on video sequences as a research field has increased in importance particularly in the last decade with the emergence of applications in sports sciences, medicine, biomechanics, animation (online games), surveillance, and security. Progress in human motion analysis depends on empirically anchored and grounded research in computer vision, computer graphics, and biomechanics. Though these fields of research are often treated separately, human motion analysis requires the integration of methodologies from computer vision and computer graphics. Furthermore, understanding and using biomechanics constraints improving the robustness of such an approach (Rosenhahn et al., 2008).

Hammer throw as illustrated in the previous chapter is not an easy technique that could be learned. Also needs like other throwing events some procedures to enable the investigator to achieve accurate data as possible. Every result depends on the method employed, and it is useful to reexamine the biomechanical parameters, in order to see the progress of technique and try to track changes in the performance using new measurement methods and technology. Agostini et al. (2003), Murofushi et al. (2005), Ohta et al. (2008), and Brice et al. (2008) worked on this idea, which is how to develop a measurement system for the hammer throw to give feedback as soon as possible while the throw is still fresh in the thrower's memory. They used the technology starting from recording wind acoustics using wireless and Microelectromechanical systems (MEMS) technology. The next level is to think about how to give the coach/thrower immediate feedback on the performance. This provides an opportunity to correct mistakes and improve performance based on quantified data, not just on the expert's subjective visual evaluation, although it is also very important.

This chapter would go further illustrating the motion analysis technology and the disadvantages that the researchers targeted to improve solutions for them. And how that affect the accuracy and time of handing results.

## 3.1 Common measurements' methods for biomechanical studies

Measurement is the procedure that facilitates the evaluation of the performance. Measurement methods can be divided into the following categories depending on the object and the properties of the measured quantity: 1) Direct and indirect, 2) absolute and relative, and 3) Deflection and null methods (Toko, 2000).

Research in computerized gait analysis is today widely supported by marker-based pose tracking systems. Basically, the camera systems used are fast (e.g., 300 Hz or more), but recorded images are normally restricted to binary information, showing positions of markers only. Computer vision already helped to create 3D body models for gait analysis (e.g., by using whole-body scanners, based on the principle of structured lighting, or by applying photometric stereo). The increasing availability of high-speed cameras supports the development of marker-less motion tracking systems, overcoming the apparent restrictions of marker-based systems (Rosenhahn et al.; 2008). Bartlett (2007) mentioned that sports biomechanists use two main approaches to analyzing human movement patterns in sport – qualitative and quantitative analysis (Bartlett, 2007).

The most common method for collecting kinematic data is motion-caption system (using video, digital video or charge-couples device (CCD) cameras), in order to record the motion of markers affixed to a moving object. That is followed by manual or automatic digitizing to obtain the coordinates of the markers, that are possessed to obtain the kinematic variables that describe segmental or joints movement (Robertson et al. 2004). Position is estimated through useing of multiple 2D images of the working volume. Stereo metric techniques correlate common tracking points on the tracked objects in each image and use this information along with knowledge concerning the relationship between each of the images and camera parameters to calculate position.

## 3.2 Problems and sources of error in motion recording

The recording of human movement in sport can be formally stated as: to obtain a record that will enable the accurate measurement of the position of the centre of rotation of each of the moving body segments and of the time lapse between successive pictures. Bartlett (2007) reported that the optical motion analysis systems are often used in the study of human movement. However, these systems are expensive, only allow measurements in a restricted volume, and the markers are easily obscured from vision resulting in incomplete data. Using the infrared systems is another method but the obstacle of the limited space, other reflections, very expensive, indoor with a lot of requirements are still the disadvantages.All this technology must inevitably pose the important social and scientific questions of how far will we go to enhance performance and when does the point arrive that we are measuring the equipment and surroundings rather than the individual athlete?.

The following problems and sources of error can be identified in 2D videography of sports movements:

**Cameras:** The 3D of the position of joint centre of rotation requires the 2D analysis of movements recorded from one camera to be done with care of Lens distortions may be a source of error, particularly at wide-angle settings on inexpensive zoom lenses. blurring of the image, camera vibration.

**Record location:**Placements of cameras must relate to the algorithm chosen for reconstruction of the movement–space coordinates. Deviations from these requirements will cause errors.artifacts from moving wires

**Body land markers:** Locations of joint axes of rotation are only estimated, based on the positions of superficial skin markers or identification of anatomical landmarks. Use of skin markers can not only help but also hinder the movement analyse, as these markers move with respect to the underlying bone and to one another. The digitizing of such markers, or estimating the positions of axes of rotation without their use, is probably the major source of random error (or noise) in recorded joint coordinates. Locating joint axes of rotation is particularly difficult when the joint is obscured by other body parts or by clothing because of skin movement

**Calibration:** Any non-coincidence of the plane of performance and the plane perpendicular to the optical axis of the camera is a source of error if calibration is performed with a simple scaling object in the plane of motion. Perspective and parallax errors need attention. Perspective error is the apparent discrepancy in length between two objects of equal length, such as left and right. Relating the 2D video image coordinates to the 3D ('real world') coordinates may be a source of error. Use of an array of calibration points is probably the most common method. Errors within the calibration volume can be accurately assessed, while those outside that volume will be larger and more difficult to assess. Errors will increase with the ratio of the size of the movement space to that of the image. All the calibration points must be clearly visible on the images from both cameras; they must also have 3D coordinates that are accurately known.

**Human errors:** digitizing errors, incorrect digitization – related to coordinate resolution and human digitizer errors – and computer round-off errors.

## 3.3 Smoothing data:

Robertson et al (2004) mentioned that the sources of the errors associated with the measurement of the biological signal. These errors or "noise" often have different characteristics. Noise is any unwanted portion of a waveform added to the main signal. For instance, the errors that associated with digitizing process are generally higher in frequency than human movement and can be removed or eliminated and leave the signal unaffected. But at the same time, care must be taken during smoothing process to the values of cutoff frequencies otherwise the data could be over smoothed, which affect badly the validity and reliability of the values represented by the curves (Figure 11). Robertson et al. (2004) and Bartlett (2007) mentioned some filter techniques and types that commonly used in sport research field:

**Fourier Series truncation** is a technique that runs in several steps consist of transforming the data into frequency domain, eliminate the unwanted frequency coefficient , then performing an inverse transformation to reconstruct the original data without the noise. This technique requires the raw data points to be sampled at equal time intervals, as do digital low-pass filters.

**Quintic spline curve fitting** is a series of polynomial curvesjoined – or pieced – together at points called knots. This smoothing technique, which is performed in the time domain, can be considered to be the numerical equivalent of drawing a smooth curve through the data points. The user has simply to specify a weighting factor for each data point and select the value of the smoothing parameter, which controls the extent of the smoothing; generally the weighting factor should be the inverse of the estimate of the varianceof the data point.

**Low-pass filter**. In movement analysis, used mainly to remove high-frequency 'noise' from a low-frequency movement signal,but reducesfrequencies above the cut-off frequency. *Digital low-pass filters*are widely used to remove, or filter, high-frequency noise from digital data.

**Butterworth filters** are often used in sports biomechanics, because they have a flat passband, the band of frequencies that is not affected by the filter.

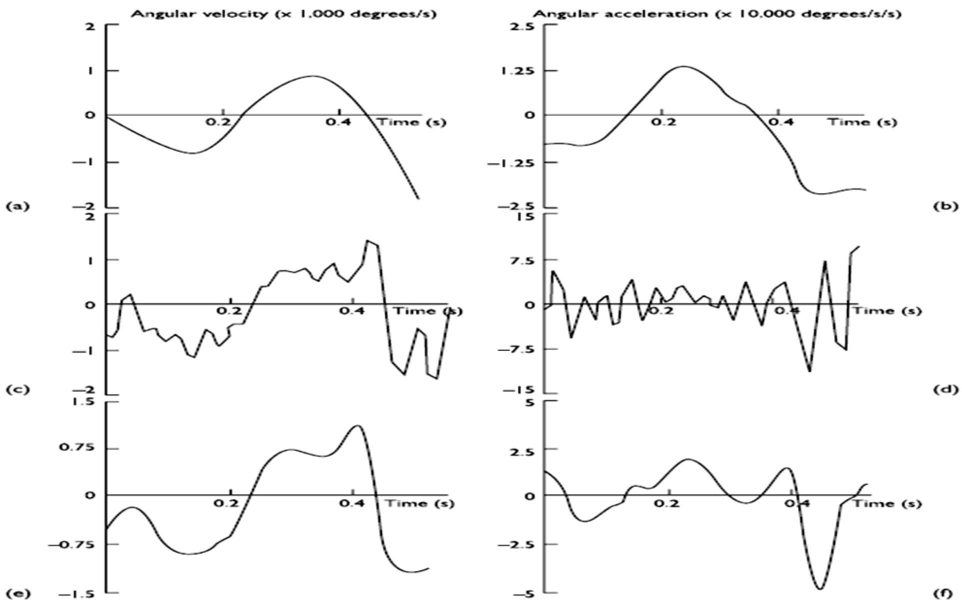



Figure 11.Graphes of smoothing examples , Over-smoothing (a) velocity, (b) acceleration. Under-smoothing (c) velocity, (d) acceleration. Optimum smoothing (e) velocity,
(f) acceleration (Robertson et al., 2004)

**High-pass filter** unchanged the high frequencies and remove or change the low ones **Band-pass** attenuates the above and lowers a range between two cut-off frequencies. Such a filter is used in EMG when there is movement artifact in the lower-frequency range and noise in the high-frequency rang.This filter do the opposite of what is **Band-reject** doing.

## 3.4 Overcoming the weakness of video record:

Traditionally the measurement of elite athlete performance is commonly done in a laboratory environment where rigorous testing of biomechanics andphysiology can take place. Laboratory testing however places limits on how the athlete performs,as the environment is sufficiently different to the training environment (James, 2006). Most common methods for accurate capture of 3D human movement require a laboratory environment and the attachment of markers or fixtures to the body segments. These laboratory conditions can cause unknown experimental artifacts.

### 3.4.1 IR cameras and diodes

The markers can either be passive (reflective) or active (light emitting). Optical systems based on pulsed-LED's measure the infrared light emitted by the LED's placed on the body segments. Also camera tracking of natural objects without the aid of markers is possible, but in general less accurate. It is largely based on computer vision techniques of pattern recognition and often requires high computational resources. Structured light systems use lasers or beamed light to create a plane of light that is swept across the image. They are more appropriate for mapping applications than dynamic tracking of human body motion. Optical systems suffer from occlusion (line of sight) problems whenever a required light path is blocked. Interference from other light sources or reflections may also be a problem which can result in so-called ghost markers (Roetenberg, 2006). IR systems could be affected with other IR sources specially sun light, that leads to use this IR systems in closed and better dark laboratories. Also in addition to the its high expanses, It has a view angle which does not cover a 360 rotational movement but by minimum 2 systems with enough data gaps need to be manipulated.

### 3.4.2 Acoustic tracking systems

They use ultrasonic pulses and can determine position through either time-of-flight of the pulses and triangulation or phase-coherence. Both outside and inside implementations are possible, which means the transmitter can either be placed on a body segment or fixed in the measurement volume. The physics of sound limit the accuracy, update rate and range of acoustic tracking systems. A clear line of sight must be maintained and tracking can be disturbed by reflections of the sound (Roetenberg, 2006).

### 3.4.3 Magnetic motion capture systems

Magnetic motion capture systems utilize sensors placed on the body to measure magnetic fields generated by a transmitter source. The 3D sensors measure the strength of the field which is proportional to the distance of each coil from the field emitter assembly. The sensors and source are connected to a processor that calculates position and orientation of each sensor based on its measured field values. This approach often is referred to as time multiplexed since the three windings are driven at different times. If three frequencies are used, then all three can be driven simultaneously. This has many advantages but also increases complexity and costs. They are always time multiplexed since there is no way to distinguish one axis from another if more than one is energized simultaneously. Magnetic systems do not suffer from line of sight problems because the human body is transparent for the used magnetic fields. Magnetic fields decrease in power rapidly as the distance from the generating source increases and they can easily be disturbed by (ferro) magnetic materials within the measurement volume (Roetenberg, 2006).

### 3.4.4 Markerless

In fact, there is a growing need of marker-less systems. Accurate marker-less motion capture systems rely on images that allow segmentation of the person in the foreground. the segmentation step makes strong restrictions to the capture environment, e.g., homogenous clothing or background, constant lighting, camera setups that cover a complete circular view on the person etc. If motion of a human is to be captured in an interaction environment, there are different conditions to be dealt with, and its clinically useful (Grest and Koch, 2008). Mündermann et al. (2008) present ICP system (Figures 12b, c), While all body segments were positioned correctly with 8 to 64 cameras. Furthermore, figure (13) illustrates the employed articulated ICP algorithm estimated joints centers in the original sequence very accurately.

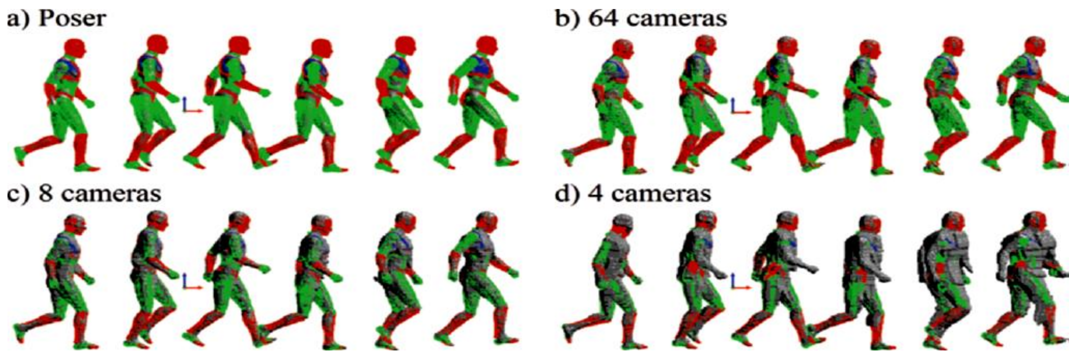



Figure 12. Tracking an articulated body in (a) the Poser and (b–d) visual hull sequences constructed with 64, 8 and 4 cameras (Mündermann et al. 2008)

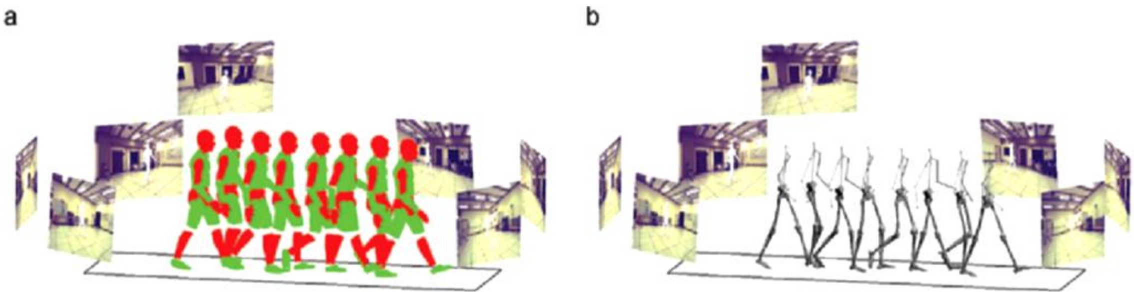



Figure 13. Articulated body matched to visual hulls. (a) Human body segments.(b) Kinematic chain (Mündermann et al. 2008)

### 3.4.5 Microelectromechanical systems (MEMS) technology

The fast rhythm of the technology and information exchange creates the need of overcoming the weakness of the common search tools for measurement and replace them with quicker, more accurate, and more flexible to any research environment method. That's agree with James (2006), where it had been emphasized that testing and monitoring of elite athletes in their natural training environment is an area of development that has been facilitated by advancements in microelectronics and other micro technologies. Whilst it is a logical progression to take laboratory equipment and miniaturize it for the training and competition environment. Furthermore, better if the method includes the interactive between the tool and the performer .

**MEMS** are integrated micro devices or systems combining electrical and mechanical components. They are usually fabricated using integrated circuit (IC) batch processing techniques and can rangein size from micrometers to millimeters. These systems can sense, control and actuate on the micro scale, and function individually or in arrays to generate effects on the macro scale.

**A sensor** is defined as a device that provides a usable electrical output signal in response to a signal also called in the literature measured or stimulus. **An actuator**, the reverse of a sensor, is a device that converts an electrical signal to an action, while **a transducer** can be considered as the device that transforms one form of signal or energy into another form. Therefore, the term transducer can be used to include both sensors and actuators. When a sensor is integrated with signal processing circuits in a single package (usually a polysiliconchip), it is referred to as an integrated sensor. They are the most advanced sensors (Mayagoitia et al., 2002).

In general machines, like treadmills, rowing and cyclingand even flumes for swimmers, allow monitoring athletes using instrumentation that cannot be used in the training environment but instead requires the athlete to remain quasi static thus enabling a constant field of view for optical devices and relatively constant proximity for electronic sensors, breath gas analysis etc. Today however by taking advantage of the advancements in microelectronics and other micro technologies it is possible to build instrumentation that is small enough to be unobtrusive for a number of sporting and clinical applications (James et al., 2004).

Hristoforou and Chiriac (2002) indicated to the field of measurement and instrumentation as increasingly interesting in the international engineering market. A lot of measurements in field sports activities are obtained using manual or semi-automatic techniques which may involve time delays or possible inaccuracies in the result. Therefore, it could be desirable, like in Olympic Games or International Championships in Athletics, to use automatic measurement techniques for detection of position of jump, triple jump length or throw of discus, hammer and javelin. Such automatic measurement could also be demonstrated to the stadium walls, which make the view sight clear for the fans.

Bouten et al. (1997), Lee et al. (2009**)**, and Takahashi et al. **(**2010**)** experimented that the **MEMS** technology is extending to every human activity even the normal daily activities to evaluate and estimate the energy expenditure andmeasure many biomedical signatures that helps to improve the life quality of the healthy and non-healthy people also without invoking personal privacy.

MEMS is , as well, employed to improve the athletes' performance by feeding the trainer and the athlete during training session with useable kinematic information. For example, was first in Golf and for human motion tracking and hammer throw. Now for more estimation and full detailed information and reducing the errors of monitoring the movement the accelerometer is not enough alone, therefore appeared the inertial Measurement Unit (IMU) (Luinge, 2002).

Some researcher used a manufactured produced sensors and commercially sold as a step to see validity of such a method to obtain kinematic data, the case of Shahbazi et al. (2008) pilot study, in which they modified Nintendo WII system to suit using in push-off glide in breaststroke swim, water environment. The output was more correlated with the a theoretical method than the motion analysis result. They were very optimistic about the use of Nintendo Wii system in future research in swimming. In the preparation of the current study stick of the same system trying to find application in hammer throw as online measurement method for acceleration of hammer head. It has been found the eligibility to obtain good result in case the acceleration of the movement in range ±3g. which directed us to the necessity of having a special sensors for our purpose.

### 3.4.6 Sensors types that common used in sport researches

As the interest in the biomechanical research ins port focuses on the kinetic and kinematic variables, the most usable sensors in use are accelerometer for measuring acceleration, gyroscope for measuring the angular displacement, Inertial measurement unit which gathers both of sensors in one unit, and the strain gauge sensor with its varieties to measure force, for instance pressure, impact, or tensile forces. Each sensor has a specific component and direction and soldering properties which is basically written in its datasheet. Briefly, a light would be focused on each on them.

#### *3.4.6.1 Accelerometer*

In recent years, advances in sensor technology havecreated exciting opportunities in the area of man-machineinterfaces andcomputer systems for detecting and measuring aspects of human movement and tools. In particular, integrated circuit accelerometershave decreased in size and cost, even with the requisite processor and power units, one can fit the device into a housing considerably smaller than a matchbox, or for surface mount units, the size of a coin .This is due chiefly to the adoption by industries such as the automobile industry where they are deployed in airbag systems to detect crashes. Micro electromechanical systems (MEMS) based accelerometers are today widely available at low cost.They arenow routinely incorporated into portable consumer devices,including Smartphones, game controllers, and personaldigital assistants. In addition to the developments in users' interaction with technology, these sensorsprovide powerful new means of interacting with technologyfor people with physical disabilities (Knight et al., 2007).

Accelerometers incorporate a mass mounted on a cantilever beam or spring, which is attached to the accelerometer housing. As the housing accelerates, the mass lags behind deforming the beam. This deformation is measured by using strain gauges, where the greater the acceleration the greater the deformation and the accelerometer output. The accelerometer output then represents the vector sum of the gravity and movment accelerations. The output that represents kinematic acceleration is used in assessing dynamic human movement activities (Knight et al., 2007).

The use of accelerometers to measure activity levels for sporting, health and for gait analysis is emerging as a popular method of biomechanical quantification of health and sporting activity and set to become more so with the availability of portable computing, storage and battery power available due to the development of consumer products like cell phones, portable music players etc. Accelerometers as kinematic systems have been able to offer comparable results to expensive optical based systems (Mayagoitia et al., 2002; James, 2006). Accelerometer is available as unisxial packages for measuring in one direction or triaxial packages for measuring acceleration in 3 orthogonal directions (Robertson et al 2004) .

#### *3.4.6.2 Gyroscope*

Rate gyroscope, a close relative of the accelerometer, measure angular acceleration about a single axis and are also used to determine orientation in an angular co-ordinate system, although these suffer from not being able to determine angular position in the same way accelerometers have trouble with absolute position. Additionally many physical movements, such as lower limb movement in sprinting, exceed the maximum specifications in commercially available units that are sufficiently small and inexpensive for such applications (James, 2006).

The term gyro is shorthand for gyroscope, the name originally given to instruments using the gyroscopic inertial properties of a spinning mass as the reference for angular rotation measurements. Today, gyro is the name given generically to any instrument that measures inertial angular rotation, MEMS (micro-machined electro-mechanical systems) gyros that measure angular rate based on the inertial properties of a vibrating mass, and optical gyros that measure angular rate based on the inertial properties of light. Gyros are used to measure inertial angular rotation. Based on measurements of the internal forces, mechanical gyros mounted within a body measure body angular rate, not angular acceleration. How do they do this? The answer is that within each gyro are proof masses that are driven into linear motion (i.e., velocity) relative to the gyro case by a motor within the gyro. Gyro case angular rate produces reaction forces on the moving proof masses that then form ameasurable composite for generating the gyro angular rate output signal. Mechanical and optical gyros measure angular rate relative to non-rotating inertial space. General non-rotating inertial space as previously defined included a general uniform gravity field within the space. Similarly, our analysis of what gyros measure was also based on the gyro being in a uniform gravity field. But what if the gravity field surrounding the gyro is not uniform (Savage, 2010).

#### *3.4.6.3 Strain-gauge force transducers*

When force is applied to a material, it deforms, this called mechanical strain. Because resistance in material length, we observe a change in the resistance when a material is deformed. This is the basic of principle of the strain-gauge. The gauge is smaller than the stamp, but equally as thin. Once glued to the surface of the structure, they bend with the material without altering the structural propertied, it is usually placed in a Wheatstone bridge circuit. The strain gauges are commonly used to measure forces in human movement with such devices as floor-mounted force plates, tension transducers, pressure transducer, and even accelerometer (Robertson et al., 2004).

#### *3.4.6.4 Inertial Measurment Unit (IMU)*

That refers to use the combination between the gyroscope sensor and accelerometer. A triaxial sensor based upon one mass has several advantages over a sensor system consisting of three single axis gyroscopes:

Only two actuators and only one mass are required, which saves energy and space.Because of symmetry, the change of sensor properties caused by temperature, humidity and wear are likely to be diminished. Also, measurement principles can be used which measure differentially, taking advantage of this symmetry. There is no mechanical interference between vibrating masses. When two gyroscopes, vibrating at almost the same frequency are assembled in one unit, mechanical interference can affect the gyroscope output (Luinge, 2002).

One such technology that has been rapidly developed in recent years is in the area of inertial sensors. These sensors respond to minute changes in inertia in the linear and radial directions. These are known as accelerometers and rate gyroscopes respectively inertial sensors use the property of bodies to maintain constant translational and rotational velocity, unless disturbed by forces or torques, respectively. The vestibular system, located in the inner ear, is a biological 3D inertial sensor. It can sense angular motion as well as linear acceleration of the head. The vestibular system is important for maintaining balance and stabilization of the eyes relative to the environment. Practical inertial tracking is made possible by advances in miniaturized and micromachined sensor technologies, particularly in silicon accelerometers and rate sensors. Miniature sensor units are placed on each body segments to be tracked. A rate gyroscope measures angular velocity, and if integrated over time provides the change in angle with respect to an initially knownangle (Roetenberg, 2006)

### 3.4.7 Using MEMS technology Advantages and weakness

#### *3.4.7.1 Immediate feedback ( as advantage)*

The most important concept in live at all is the time, as well as for is the feed-back mechanism,with MEMS technology most of mentioned weaknesses of other methods are overcome, which means simple to use, in several and varies situation and environments, not expensive, and with monitoring program playing back the performance plus enough kinetic and kinematic data are available in several minutes, which also emphasize the individuality in the educational or training purposes. That is perfectly illustrated in the athlete coaching system model that designed by Gao et al. (2009) (Figure 14), to competent with designed multidimensional acceleration sensor for coaching shot-put. In throwing hammer, there are no such an experimental research about the effect of feedback aids on the throwing distance or the performance except Agostini et al. (2003) and Maryam et al. (2009). In spite of the efforts of Japanese team of Murofushi to develop the hammer system, they didn’t carry out till the moment of writing this study an experiment to till how their equipment affects technique and personal record.

Maryam et al. (2009) compared between the verbal and the video feedback on two groups of hammer and discus thrower beginners on the throwing distance. The effect of the video feedback reached about (6m) in case of throwing hammer comparing with the verbal instruction about (5m). the difference seems not to be big, but regarding to the level of the participant and the duration of the program (10 practice sessions), it represents achievement.

Harding et al. (2008) revealed in their study 6 dimensions and 20 sub-dimensions relating to the practice community’s perceptions of 3 major themes that emerged during interviews. The themes included: 1) State of the current subjective judging system, 2) Automated feedback and objective judging system, and 3) Future direction of the sport. who refere to the dilemma with video based analysis of sport specific Key Performance Variables (KPVs) is the labour intensive nature of calculation and the associated time-delay in information feedback. The method of calculating KPV information using Micro-electrochemical systems (MEMS) based triaxial accelerometers and tri-axial rate gyroscopesis developed by Australian Institute of Sport (AIS) sport scientists. Through the results they emphasized the theory that a MEMS based feedback system could assist judges by providing accurate, electronic “memory boards by quantifying and displaying objective information on sport specific KPVs. The results of this study provide the practice community an initial public forum to describe its perceptions to future automated judging concepts, nominating them to be the primary determinants of change, technological or otherwise, within their sporting discipline.

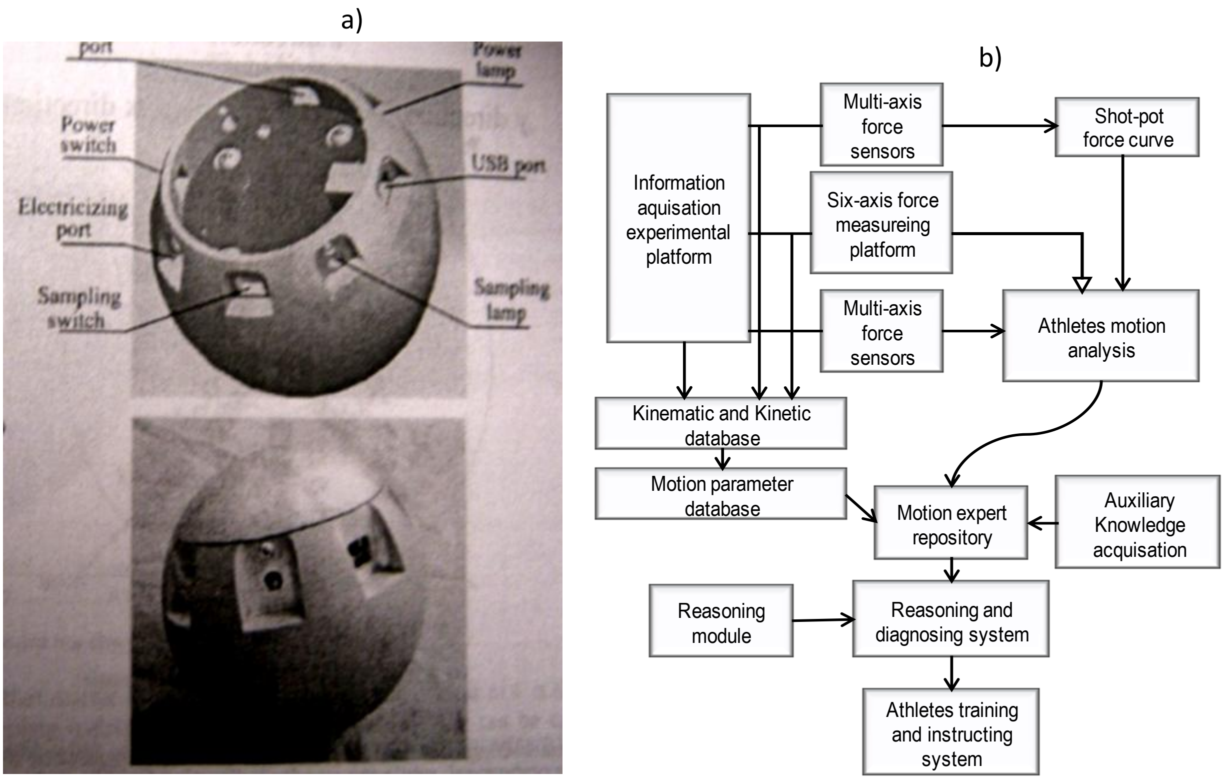



Figure 14. a) Design of the fabricated digital shot put, and B) the flow chart of the athlete coaching system that serves the output from the Shotput Gao et al. (2009)

### *3.4.7.2 Factors effecting measurement accuracy (as weakness)*

These wires may be not comfortable to be worn during performing from the first time, hence wireless was the best solution, at the same time it enables the monitoring the performance curves online. This solution is supported by Kerwin (2009), and illustrated how wireless technology is addressing problems associated with collecting biomechanical data in a training environment to aid understanding, and enhance feedback with the ultimate goal of improving sporting performance. These sensors resample in some properties that affect the output signal, which in turn affect the accuracy if it’s not corrected. Roetenberg (2006) indicates that noise and bias errors associated with small and inexpensive sensors, which make it impractical to track orientation and position changes for long time periods if no compensation is applied.

**Bias:** It’s defined as output signal bias which is the observed signal when no input is present. In case of gyro it can be measured when the board is stationary. Regarding to the rate of the rotation of the Earth is 0.0041666 degrees per second, it may be the source of voltage, but not for every gyro, because it depends on the sensitivity. In case of accelerometer, it is not easily obtained since one (g) of acceleration due to gravity. Thus, the bias would be the difference between the observed output signal and one (g).

**Misalignment:** Resulted from mounting the sensor or the electronic board not orthogonal, This means that rotation about one axis will cause signals to be measured on other axes too.

**Non-linearity:** The devices do not produce a perfectly linear response over the entire range of sensitivity. This is usually about 0.5% of full scale.

**Noise:** The faster you sample a signal the more important noise will become as a factor.

**Change in temperature**: This should allow to find the bias and how the bias changes with temperature. This will require turning off the board and letting it cool down to room temperature between each test. In case of strain force sensor, changing in the material's diameter relatively associated with energy output as temperature increase. This can be corrected with resistances in the bridge.

**Gyro level arms:** This refers to the linear displacement of the sensors from the actual center of rotation. This is a difficult calculation but basically you need to know the orientation of the board with respect to the origin of the reference frame in which the rotation actually takes place. Then the measured rotations can be converted into actual rotations based on the lever arms and angles.

## 3.5 Previous studies of Hammer throw measurement systems:

Agostini et al. (2003) tested a cognitive training strategy for hammer throw based on acoustic stimulation to enhance the performance in hammer throwing, which induces the targeted mental representation of motor processes. A microphone was mounted on the wire near the hammer head, that microphone's cable was connected to a audio cassette recorder through a plug on the glove of the thrower, at release the cassette remains with the thrower while the microphone flies with the hammer. The results showed for all athletes significant improvement of performance (average distance of throwers), between 0.57m and 0.934m increase. The study presents a simple method of training and giving feedback. But still not accurate while the thrower can turn faster and faster but can't achieve the same distance because of the other important factors like height and angle of release for example. For correcting the technique and analyzing the throw another methods must to be add accompanied with this system.

Murofushi et al (2005) compared the radius of curvature and the estimated hammer head speed as measured by sensors attached to a hammer with those calculated by video image analysis. The participant was the Japanese record holder (83.47m). He threw a hammer (7.28 Kg) with sensors toward a net. The tension resulted by the force exerted along the length of the hammer wire was measured using tensiometer and the angular velocity by 2 single-axes acceleration sensors. The sampling frequency of the data recorder was 500Hz. These throws were filmed with 3 high speed cameras 250f/s. They have observed that the tension F increased gradually over the turns in concert with the beginning of double support phase (DS). It reached the peak from the low point up until the beginning of the single support phase (SS) then a decrease tendency appeared. For the angular velocity the values obtained from digitizing showed change in similar to sensor's, but in turns 3 and 4, the peak was earlier. Whereas the values of the radius of curvature obtained from the sensors (r) decreased in DS and increased in SS, in contrast to those obtained from the video (R). Furthermore, r was longer than R. Regarding to the hammer head speed obtained from the sensors differed from the actual obtained from the video and a sudden decrease was observed. Measurement of angular velocity by the sensor takes only the rotational movement of the hammer. But the authors believed that the obtained data are reasonable. On the other hand, in regard to the speed of the hammer head, even though they couldn't obtain its magnitude at release, they were able to obtain approximate changes during the throwing operation in a short time. The system using sensors attached to a hammer will enable athletes and coaches to interpret the data about each throw while it is still fresh in their minds.

Murofushi et al. (2007) measured the ground reaction force using eight force plates (EFP-S-10KNSA7: Kyowa Electronic Instruments 600 ×900 mm, 500 Hz) and wire tensile force using tensiometer 500 Hz. Three hammer throwers: the Asian record holder and two university athletes. They were filmed using three high-speed video cameras (HSV-500C3: NAC ImageTechnology 250 Hz). The displacements of the hammer head and the athletes' centres of mass were calculated using 3D analysis procedures. The authors reported that the wire tensile force gradually increased with each turn. But the ground reaction force, which consisted almost entirely of a vertical component, did not increase except during the delivery phase when it behaved in a similar manner to the wire tensile force. The peak of the wire tensile force almost coincided with the middle of the peaks between the right and the left foot force in each turn.The Asian champion's vertical ground reaction force of each foot on each turn showed a clear transfer of pressure from the right foot to the left foot that exceeded that of the university athletes. The horizontal components of the ground reaction force in the throwing direction and the lateral direction were mainly produced by the right foot (although the left foot also contributes) during the double support phases with the exception of the delivery phase. It would appear that throwers will be able to maintain a balance between the hammer head and their body by lowering their body during the single support phases and by consciously keeping their body at a certain height and rotating their body by the right foot during double support phases.

Brice et al. (2008) presented a method that is capable of measuring cable force in real time and, as it does not interfere with technique, it is capable of providing immediate feedback to coaches and athletes during training. A single general-purpose constantan alloy gauge (3.18 ×1.57 mm; Vishay Micro) was mounted on the wires of three hammers to measure the tension. An elite male hammer thrower executed three throws with each hammer. The output was recorded by a data logger. At the same time the throws were captured by three 4.2 Phantom high-speed cameras genlocked and sampling at 100 Hz. A manual digitizing of the hammer's head for the five best throws was carried out using ABAS to get the 3D positions. The force acting on the hammer's head was calculated from Newton's second law of motion and this was compared with the force measured via the strain gauge. The results showed that the two forces were essentially the same qualitatively, although the measured force showed more detail in the troughs of the force–time curves. As well the average difference over the five throws was 76 N, which corresponds to a difference of 3.8% for a cable force of 2000N. In future research it will hopefully be possible to determine if the small differences between the detail of the measured and calculated cable forces is an artifact of an athlete's style and not some error in the strain gauge signal. It is hoped that the system can be used to provide real-time feedback to athletes on their progress in the hammer throw.

Ohta et al. (2008) have been developed a Dynamics-based force sensor using accelerometers which. In this study the authors have applied this method to hammer throw training aid integrating small sensors, signal processing, short-range wireless transmission, wearable data-logger and biofeedback training system. During throws the throwers are hard to realize angular acceleration of hammer, which mainly affects the speed of the hammer head, in force level because the centrifugal acceleration composes most of the wire tension. Without the feedback of the information, which athletes can't detect by themselves, throwers may exert effort without the effect. However, measuring range for consumer gyro sensors is generally restricted up to ±300 deg/s. It is in general too small for measuring sports movement. Accelerometers provide enough range for measuring sports movement on the contrary and give a suitable data set, in particular, for inverse dynamical calculation online. Using this method it also realizes the force display devices, which are able to make virtual reality environment.

## 3.6 Related Studies in throwing events

Yang et al. (2005) apply instrument and equipment to measure dynamic parameters in the course of putting. The result of this study is to make an electronic pressure device fixed inside a shot. According to non-electric measuring principles, a computer is used to analyze the acquired signals after their amplification, taking sample and no transmission so as to measure the dynamic parameters that shot-putters have strength on their arms. They may work as theoretical basis of teaching and training. In the mean time they can also help coaches to give technological diagnosis of shot-putters and make a scientific plan of training. Only in this way can shot-putters in China catch the advanced level of the world and win good scores at the Olympic Games.

Song et al. (2006) present anovel three-axis force sensor for measuring the throwing forces of shot-put athletes. The shot-put sensor has been designed and fabricated with almost the same size and weight as the standard shot for open males. Instead of using a common shot, the shot-putters can use this shot put sensor to make their throws. The sensor can simultaneously detect applied forces along three orthogonal directions with reasonably high accuracy. With the help of a commercially available high-speed photography system, field tests have been performed. The experimental results show that each phase of the throwing motion can be clearly identified by analyzing the force curves and it is easy to distinguish between throws levels. As a result, the shot-put sensor serves as a powerful tool for coaches and sports scientists to make scientific researches on shot-put techniques. It also provides an intuitive and reliable guidance for the shot-putathletes to improve their skills.

Gao et al. (2009) aimed to present a shockproof accelerometer-embedded shot, called digital-shot, developed for the acquisition of the multidimensional acceleration simultaneously from the motion of the shot-put for advanced training of field athletes. It has been designed and manufactured to meet the standard in external dimensions and weight specified by the International Association of Athletics Federations for open females. Using wavelet transformation, the characteristics of acceleration signals during the pushing phase can be extracted to provide constructive guidance for athletes to improve their skills. It also functions as a new platform for the development of advanced shot-put athletes training and coaching system and for the research of human motion modeling. The system has been validated in field experiment showing its feasibility, accuracy and effectiveness.

Ganter et al. (2010) studied the application of a full body inertial measurement system (IMS) for a kinematic analysis of the discus throw. Three throws done by student thrower were simultaneously recorded using an IMS and high-speed video (HS). The IMS (MVN; Xsens Technologies, Netherlands) consists of a suit equipped with 17 inertial sensor units (MTx) and two transmission units. Each unit integrates 3D linear accelerometers, 3D rate gyroscopes and 3D magnetometers. The results emphasize the potential of this approach for analysis of complex movements in sports. Like the discus throw, valuable application of the system is also expected for the rotational movements performed in shot put or hammer throw. Limitations exist for the accurate detection of the last foot contact related instant and the discus release instant using the IMS data. Just the accuracy has to be evaluated for the assessment of kinematic data in particular in high-level athletes and should evaluate a possible interference with the movement.

# 4 Research methods

This chapter deals with the research methods of the study, including research design,participant, pilot studies, procedures, statistical analysis, parameters and calculation.

## 4.1 Research Design

The current study is a case study which was carried out in order to diagnose the characteristics of the kinetic energy by analyzing throwing trials of elite female hammer throwers. The second part is the procedures to calibrate and validate the Measurement information System (MS).

## 4.2 Participants

Three German female hammer throwers participated see table (5). They train at the sport club SC Eintracht Frankfurt/Main under supervision of coach Michael Dehyle. Betty Heidler and Kathrin Klaas are considered top athletes in germany and internationally, in table (6) the personal record improvement could be followed. After recording the trials, the trials of the third thrower were delayed to another publication.

Table 5. Participants characterization (taken from the personal questioner and the rank according to http://www.all-athletics.com/en-us//current-rankings?gender=F&evtg=40)

| Athlete Name | Betty HEIDLER | Kathrin KLAAS | Mareike NANNEN |
|---|---|---|---|
| Data of birth | 14thOctober 1983 | 6thFebruary 1984 | 2ndJanuary 1990 |
| Hammer throw Rank | 1 | 7 | 151 |
| Height (m) | 1.75 | 1.67 | 1.79 |
| Body mass (kg) | 85.5 | 74.3 | 68.5 |
| Personal record (m) | 79.42 WR | 76.05<br>London 10.08.2012 | 62.28<br>Halle 20.05.2012 |

## 4.3 The pilot studies

the current study required pre-test of the equipments. One of them was for testing cameras under video-record circumstances. The second was for testing the measurement system and make the needed modifications.

### 4.3.1 Video record for three hammer throw competitions using 3 cameras (Casio Ex-F1 300Hz)

It's well known that throwing hammer requires a wide area for performance and extra area for safety. Many of researchers who interested in studying the biomechanical parameters of hammer throw event during competition, since the thrower exhibits the best as much as he can for a new record, have been enforced to locate their cameras (two or maximum three) far away (reached 70m) from the thrower due to the competition rules. Some others are interested in studying more specific parameters by using measurement systems, therefore competitions were not the right circumstance for the targeted purpose, thus they carried out the video record indoor with distance from 6 to 10m between the cameras and the throwing circle. That was a similar case of the current study in addition the purpose of studying each body-segment individually not only thrower center of mass.

Table 6. The Performance development of the Three Heidler, Klaas and Nannen over the sesones as reported in IAAF

| Season | **Performance** | **Place** | **Date** |
|---|---|---|---|
| | | **Betty Heidler** | |
| 2012 | 78.07 | Ostrava | 24.05.2012 |
| 2011 | 79.42 | Halle | 21.05.2011 |
| 2010 | 76.38 | Barcelona (O) | 30.07.2010 |
| 2009 | 77.12 | Berlin | 22.08.2009 |
| 2008 | 74.11 | Wiesbaden | 31.05.2008 |
| 2007 | 75.77 | Halle | 19.05.2007 |
| 2006 | 76.55 | Leverkusen | 28.07.2006 |
| 2005 | 72.19 | Schönebeck | 29.07.2005 |
| 2004 | 72.73 | Athína (Olympic Stadium) | 25.08.2004 |
| 2003 | 70.42 | Mannheim | 21.06.2003 |
| 2002 | 63.38 | Mönchengladbach | 29.06.2002 |
| 2001 | 60.54 | Braunschweig | 07.07.2001 |
| 2000 | 56.02 | Halle | 27.05.2000 |
| | | **Kathrin Klaas** | |
| 2012 | 76.05 | London (OS) | 10.08.2012 |
| 2011 | 75.48 | Ostrava | 30.05.2011 |
| 2010 | 74.53 | Pretoria | 12.03.2010 |
| 2009 | 74.23 | Berlin | 22.08.2009 |
| 2008 | 70.39 | Mannheim | 21.06.2008 |
| 2007 | 73.45 | Halle | 19.05.2007 |
| 2006 | 71.67 | Schönebeck | 01.01.2006 |
| 2005 | 70.91 | Mannheim | 18.06.2005 |
| 2004 | 68.01 | Manchester (SC) | 24.07.2004 |
| 2003 | 63.72 | Regensburg | 09.08.2003 |
| 2002 | 57.21 | Weinheim | 22.06.2002 |
| | | **Mareike Nannen** | |
| 2012 | 62.28 | Halle | 20.05.2012 |
| 2009 | 59.21 | Göttingen | 28.06.2009 |
| 2008 | 58.51 | Halle | 24.05.2008 |
| 2007 | 55.10 | Schweinfurt | 24.06.2007 |
| 2006 | 54.46 | Halle | 21.05.2006 |

The main objectives of the pilot study were to 1) test our available cameras and the best appropriate setting for indoor and outdoor use. 2) determine the least number of cameras could be relyingon.3) determine the best distance between the camera and thrower based on the view angle of the camera, and 4) check the type, size and color of the body-land markers that facilitate tracing operation during the analysis.

### 4.3.2 Measurement information system (MS)

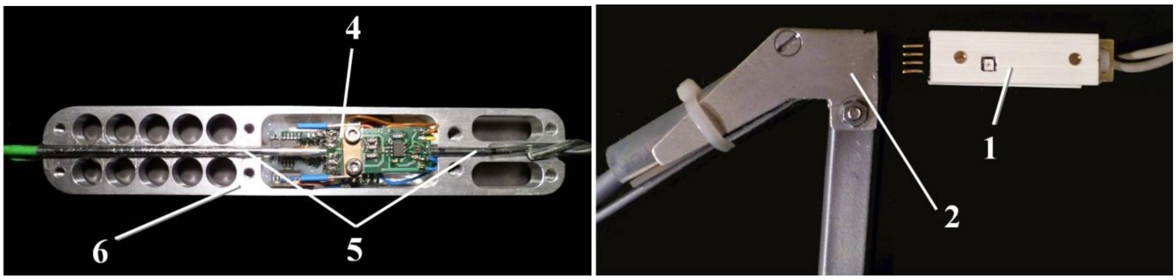
In the way to this system, many steps finally confirmed the requirement to have a special system to be produced. The author started testing the joystick of the Nintendo Wii as a measurement unit, and a program has been used to convert the analog into digitals, which is received by the Bluetooth. The digitals afterwards were converted to present the values of the acceleration in (g) units. This primary pilot study, which was carried out in Mannheim for four elite youth hammer throwers, proved that the Nintendo Wii joystick is not a suitable measurement unit for Hammer Throw performance. Its limitation in measuring, which is up to (±3g) doesn't fit with high speed of a sport like the Hammer Throw even when it is held in hand. As a result, the targeted device has been designed.

#### *4.3.2.1 The component and technical details of the measurement system*

The system idea and the initial design was presented by the author is, thenproduced and developed in the fine electronic workshop **(WWE)** in Konstanz University. It is considered a modification of the systems, which are produced by Murofushi (2005, 2007) and Brice (2008). This system has 7 sensors fixed on the handmade chip, where the resistance,12 bit analog to digital converter (ADC) is also fixed. It was produced to measure the acceleration in 3D, the angular velocity around three axesin x-, y- and z-directions, and finally the strain force sensor (SFS) is to measure the strain in the wire by sensing the change in the wire's diameter under pulling-hammer effect. The sensors chip is covered by an Aluminum box, and the wire go through this box. The total weight of the box the electronic parts is 0.225 Kg, in addition to official weight of the hammer (4 Kg), see figure (15). For more details about the electronic chip and the inteir design see appendix (7.1).

When the athlete is ready, she plug in the wire then press a mini button connected with red-LED as a start signal. The signal transfer frequency is 1952 Hz. At release instant, it is unplugged and signal transfer stops, then the data is saved on the mini SD (see Figure 16). The signals are afterwards exported from the data logger to be used.

a)




b)

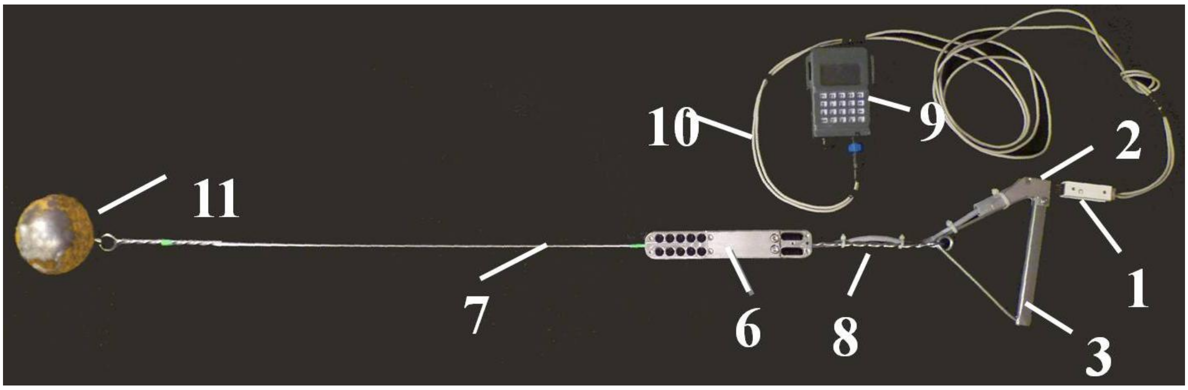



Figure 15. Measurement information system :a) in parts and b) complete; where the numbers indicate to the component 1. the male-plug with red-LED, 2. Femal-plug under metal cover, 3. Hammer handle, 4. Electronic chip which include MEMS parts,5.The hammer wire go throgh the electronocs, 6. The Aluminum holder, 7&8. The rest of the hammer wire, 9. Data logger,10. the wire between the data logger and the plug, and 11. Hammer head

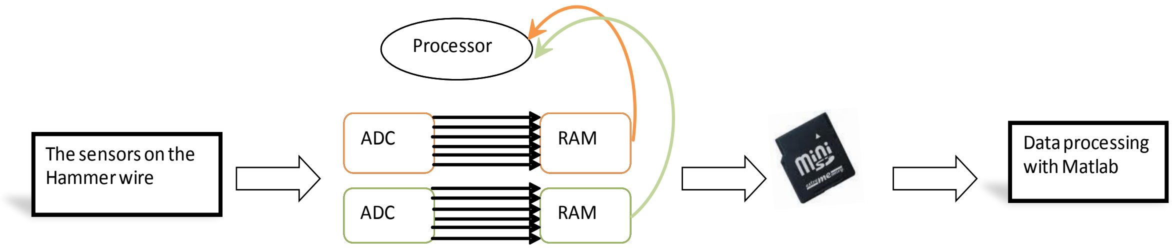



**Figure 16. Technical steps from the signals to reach the end form of the data**

#### *4.3.2.2 Accelerometer and Gyroscope adjustment and calibration*

For calibrating and defining the directions related to the data from the logger, the box is separated from the hammer, so the SFS signal channel is available to connect a magnet sensor. its signal is saved on the same data logger and with the same frequency. Both of magnet sensor and the electronic box (each time different position) mounted on a 26 inch wheel as in figure (17) .On the axis of rotation, a 60-teeth-gear is fixed (each tooth 6˚). This magnet sensor shows signal just in case of contacting metal surface (gear tooth). Each box position tested two sensors (Accelerometer and Gyroscope), after pressing the button, the wheel wasrotated manually then stopped and unplugged.

The data was output from the data logger and prepared to be calculated as following:

$$acceleration(m/s^2) = \frac{\left(\frac{\text{ADC output} \times suplementaryvoltage}{2^{12}} - \text{zero G voltage}\right)}{sensorsensitivity} \times 9.81 - offset \quad \text{-----------5}$$

$$angularvelocity\left(°/_s\right) = \frac{\left(\frac{ADCoutput \times suplementaryvoltage}{2^{12}} - zerovoltage\right)}{sensorsensitivity} - offset \quad \text{-----------6}$$

1. Convert the digitals output into angular velocity unit (°/s), as well as into acceleration unit (m/s²) by using equations (5 and 6).
2. Calculate angular velocity of the magnet sensor.
3. Liner regression between the output from previous steps.
4. Use equation model as a calibration.

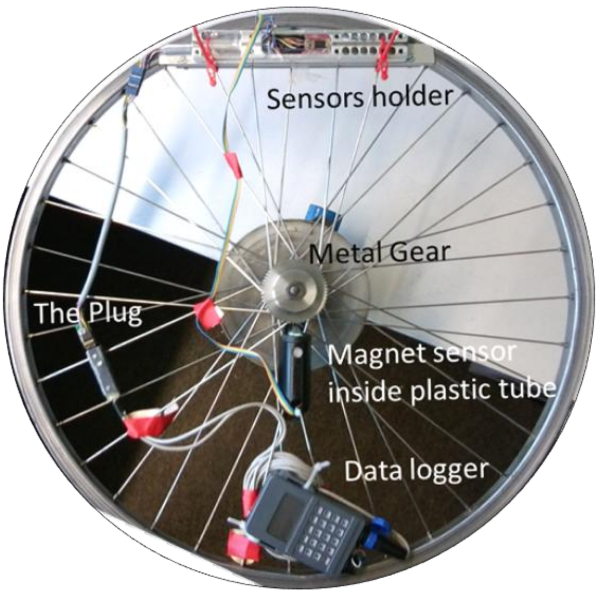



Figure 17. Gyros and accelerometers calirating process

#### *4.3.2.3 SFS adjustment and calibration*

The structure included undefined component substance like the glue and soldering, but the calibration process involve all of this factors in the output. The heating factor due to straining is treated to be equalized by resistance and removes the effect of temperature. In order to calibrate or adjust the SFS, another strain force sensor also produced by the university was used , then the regression (Figuer 18) between both outputs was carried on to have the next equation model , equation (7) was used to convert the digital output of the SFS into Newton unit.

$$Strainforce(N) = 0.6(SFSoutput) - 520.6 \quad \text{------------ 7}$$

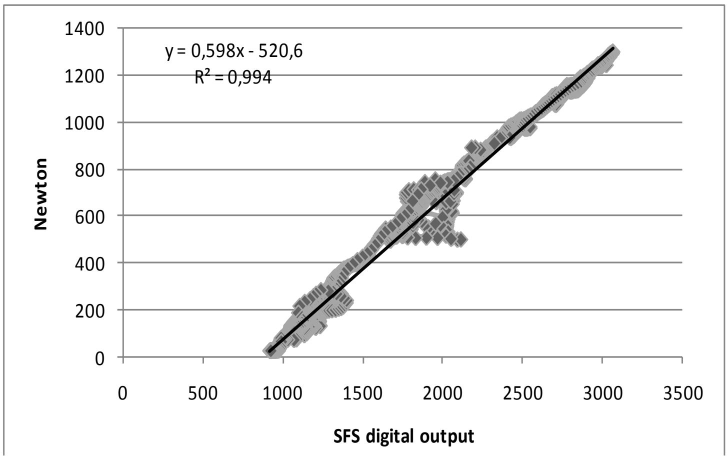



Figure 18. the residual line of regression between SFS and the other strain sensor

## 4.4 Procedures

### 4.4.1 Preparing the Location and positions of cameras

The main experiment was carried out in December 2011 (Sport- und Freizeitzentrum Kalbach) in Frankfurt am Main, 6 digital high speed cameras Casio Exilim Ex-F1 (300 Hz) were located around the throw hammer cage with defined angles among them and (6m) far from the center of the throwing circle. And one from above attached to a bar, which was excluded after that from digitizing after because of technical problems found in the SD card.The net was lifted up for a clear view, the throws were performed toward a special-designed Curtains, which prevent the thrown hammer to react in toward the thrower after impact. Figure (19) shows a sketch of the place with camera distribution.

### 4.4.2 Anthropometric measurements

Anthropometric measurements form was driven from the Simi Anthropo Model version 1.2 (see Figure 20). Simi Anthropo program calculated the masses and the center of mass of 15 body segment based on modified model of Hanavan and Clauser, as well as the body center of mass according to the measurement that had been input in the program. The body and segments lengthes are in units Meter, which is used to calculate segment dimensions. The body and segments masses are in units Kilogram, which as used to calculate the segment masses and inertia properties. The resulted file of each thrower was used individually in Simi motion 3D program in purpose to calculate the velocities of each segement and throwers center of mass.

### 4.4.3 Marker-set.

Marker-set and positions protocol was taken from Simi motion 3D documentation as table (7) and figure (24) show. These markers were used for tracking motion during motion analysis. A special markers (passive and active) were used as a body-land markers, twenty nine specific white LED lamps as individual and in chains were provided with mini rechargeable batteries at the Workshop of the

University (Figures 21 and 22), in addition twelve balls (30mm size) painted in Neon-green non-reflective-color (Figure 23).

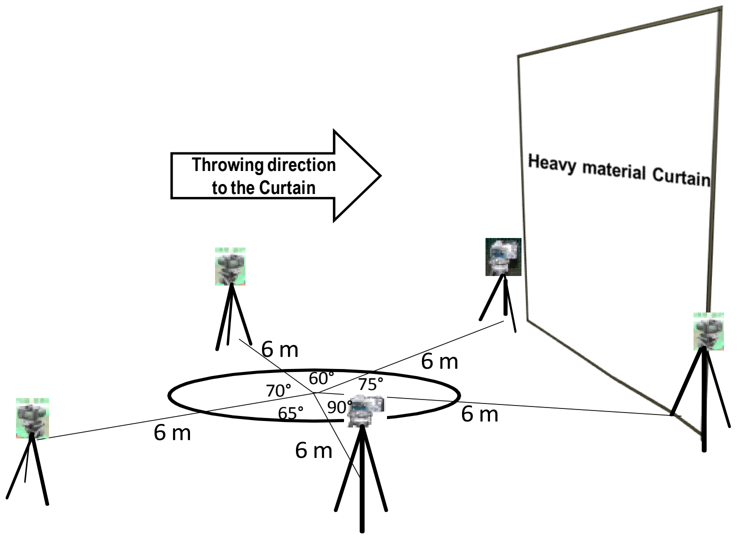



Figure 19. the location of performance with cameras distribution

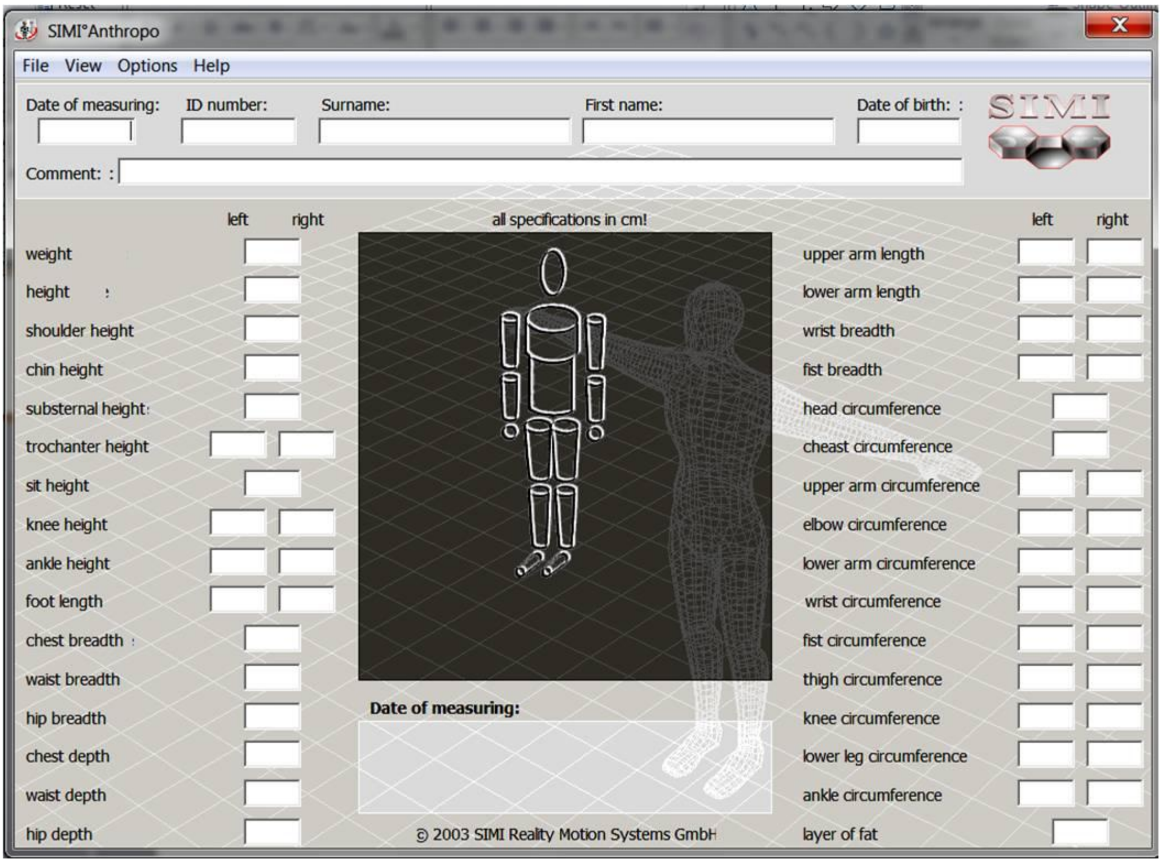



Figure 20. Anthropometric measurement protocol (screen shoot from the program interface) shows the needed data like the personal data of the thrower on the top, then the two columns on the write and the left of the model show the titles of the measured segments

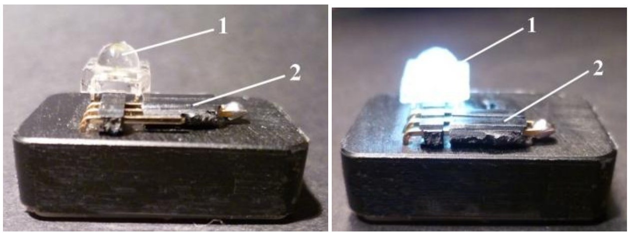



Figure 21. On and off-turned individual active marker
1) LED mounted on boxes, which are the mini rechargeable-batteries holders, and 2) the plug

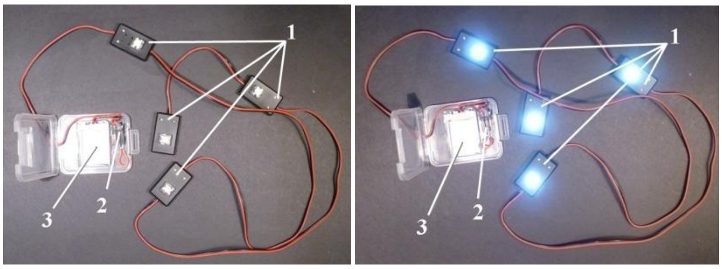



Figure 22. On and off-turned  chain of active markers includes
1) 4 LEDs, 2) the plus, and3) one rechargeable batteries in a white flat box

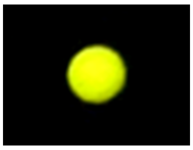


Figure 23. Passive marker painted in  Neon-green color

Figure 24. Body land markers positions on the three throwers include the passive and the active

Table 7. Marker-set and positions protocol was taken from Simi motion 3D documentation

| | |
|---|---|
| *Forefoot right/left* | directly over the 2nd metatarsal, approximately one or twocentimeters posterior from its head so as to allow for the metatarso-phalangealjoints to flex without the marker being disturbed. |
| *Foot tip right/left* | on the tip of the second toe, or on the front tip of the shoe. |
| *Heel right/ left* | on the posterior surface of the calcaneus with the markerhovering just above floor level when the foot is flat against the ground. |
| *Maleolus lateralis right/left* | tip of the lateral malleolus of the fibula. |
| *Maleolus medialis right/left* | 5mm distal to the tibial malleolus. |
| *Shank right/left* | approximately half way up the anterior surface of the shank. |
| *Condylis lateralis right/left* | on the posterior convexity of the lateral femoralepicondyle. |
| *Condylis medialis right/left* | on the posterior convexity of the medialfemoral epicondyle. |
| *Spina iliaca anterior superior right/left* | directly on the anterior superior iliacspine. |
| *L4* | on the lower back, mid-way between the posterior superior iliac spines. |
| *Trochanter major right/left* | on the lateral hip placed over the greatertrochanter. |
| *C 7* | on the superior palpable point of the spinous process of the seventhcervical vertebrae. |
| *Manubrium sterni* | on the front of the neck centrally on the collarbone (orclavicle) just below the throat, in level with the 7th cervical vertebrae. |
| *Processus Xiphoideus* | on the lower end of the breastbone. |
| *Th8* | placed on approximately the middle of the back directly opposite theProcessus Xiphoideus marker. |
| *Acromion right/left* | placed on top of the acromion process. |
| *Triceps right/left* | on the posterior surface of the upper arm, approximately 10-12 cm down fromthe glenohumeral joint (depending on length of arm). |
| *Biceps lateral right/left* | placed approximately in the middle of the lateral sideof the upper–arm when the arm is held in the anatomical position. |
| *Head front side right/left* | the front head markers should be placed above thetemples. It is recommended constructing a headband with all four headmarkers with all the markers equally distant to each other. |
| *Head backside right/left* | diagonally opposite the front head markers. |
| *(Elbow medial right/left)* | placed on the medial epicondyle of the humerus. |
| *Elbow lateral right/left* | placed on the lateral epicondyle of the humerus. |
| *Wrist medial right/ left* | placed on the medial side of the wrist joint, nearstyloid process of ulna. |
| *Wrist Lateral right/left* | placed on lateral side of wrist joint, near styloidprocess of ulna. |
| *Hand* | just before the distal end of the 3rd metarcapal bone. |

### 4.4.4 Calibration, video record and data input.

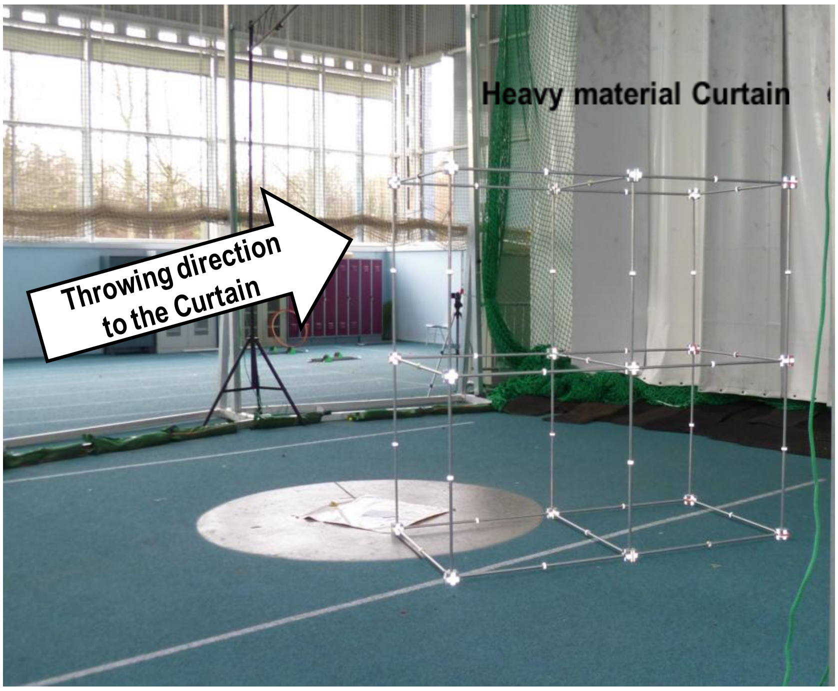



Figure 25. left-side view of the throwing location, where the calibration cube was located 50 cm from center of the circle

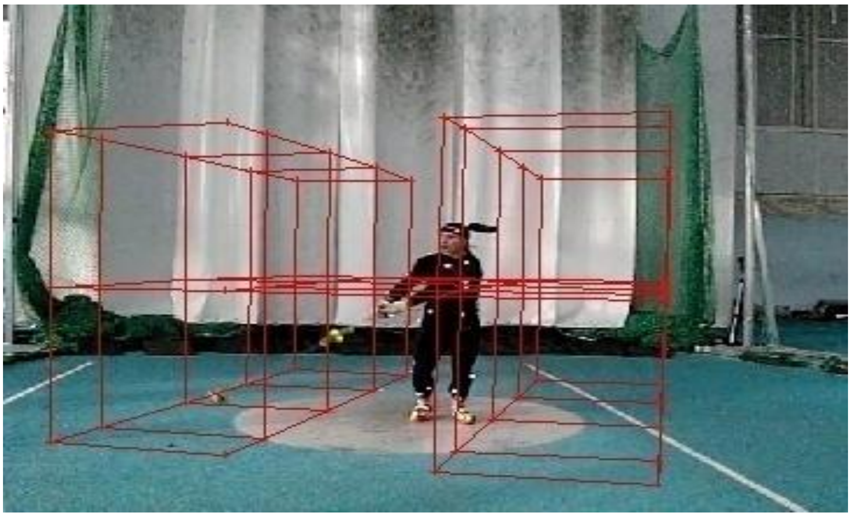


Figure 26.Calibration points of the total 60 point after recording it in 4 locations and digitizing the points with Simi 3Dmotion analysis

1. The data logger of the hammer measurement system was attaches to the athletes back, the wire fixed along the right arm, and the plug attached to the wrist, which was better for the plug safety and easy separate during release.
2. Each thrower was asked to perform six trials as best as possible, with a pause in between for resetting the data logger and preparation for the next trial. They also were asked to name their best trials among the six.

3. A calibration unit with dimensions (2x2x1 m) has 18 points positioned in 4 locations to cover the whole performance area, wherein each camera can see almost all the points clear. The total calibrating point would be 60 for an area (3.5x3x2 m) (Figures 25 and 26).

#### 4.4.5 Digitizing the recorded video, and data output from MS.

1. The red LED, lamp which attached to the measurement system, is used to synchronize among the cameras to utilize the first frame for analysis.
2. The mentioned-performances by athletes were digitized using Simi 3D Motion Program version 7.5.300 to get the 3D coordinates of the body segments and the hammer.
3. Exporting digital data from MS and convert data using equations (5, 6 and 7) in addition the absolute values of the accelerations and angular velocities.
4. The center of masses of the 15 body segments and the thrower center of mass were calculated with the Simi 3D motion program based on the modified Hanavan-Clauser Model.
5. Exporting the 3D data and correct them using Matlab program.
6. Re-import the corrected data into SIMI 3D motion program to apply the Butterworth filtter with 7 cutoff frequencies from the absolute values of velocity and acceleration curves from high peaks.
7. Calculate the kinetic energies of segments, body, and HH using Excel and Matlab. The masses of each segment were taken from Simi Anthropo program output.

$$KE = {}^{1}\!/_{2}\, mv^2 \qquad \text{------------------------8}$$

8. The distances of the used trials were estimated by using throwing distance equation, regardless air resistance because the performance was indoor (Otto, 1994).

$$Distance = \frac{v^2}{g} \cos\theta \ \left(\sin\theta + \sqrt{\sin^2\theta + \frac{2gh}{v^2}}\right) \qquad \text{------------------------9}$$

Where v, h, and Ɵ is the velocity, height, angle of release respectively and g is the gravitational acceleration (9.81m/s²)(Otto, 1994). First group trials which exceeded 57m and second group trials which less than 52m (see Table 8).

Table 8. Description of the biomechanical parameters at release and the estimated distance

| Trials | | Velocity (m/s) | Height (m) | Angle (°) | Estimated Distance (m) |
|---|---|---|---|---|---|
| First group | K2 | 25.7 | 1.83 | 36.6 | 66.83 |
| | H4 | 24.3 | 1.88 | 37.3 | 60.40 |
| | H5 | 24.1 | 1.80 | 34.0 | 57.40 |
| Second group | H1 | 23.1 | 1.74 | 29.2 | 49.33 |
| | H3 | 23.4 | 1.56 | 28.0 | 49.04 |
| | K3 | 22.9 | 1.63 | 29.7 | 48.70 |
| | K6 | 23.8 | 1.57 | 28.7 | 51.36 |

### 4.4.6 Statistical analysis

- After importing data to the excel sheet, the data was classified twice once according to DS and SS phases, and the other according to HP and LP phases.
- The linear correlation coefficients between body segments kinetic energy BSKE (H, UTO, LTO, RA, LA, RL and LL) with each of BKE and HHKE as well as the correlation between BKE and HHKE were computed using SPSS software (v19) for each phase of the trials of both athletes.
- The simple regression analysis between BKE as independent variable and HHKE as dependent variable was performed by using SPSS software (v19) for release phase (the duration between LP4 and Release instant) for the trials of both athletes.
- The stepwise regression analysis between BSKE (as independent variables) and HHKE as dependent variable was performed by using SPSS software (v19) for release phase for the trials of both athletes.
- The average contribution percentages for the BSKE to the HHKE and BKE to the HHKE were calculated for each phase using the following equation

$$Contributionpercentage(\%) = \frac{BSKE}{HHKE} \times 100 \qquad \text{-------------------------10}$$

$$Contributionpercentage(\%) = \frac{BKE}{HHKE} \times 100 \qquad \text{-------------------------11}$$

- The contribution values were the mean of contribution values in each phase.
- The mathematical difference between the body center of mass KE and this for hammer center of mass at release.
- Illustration of correlation coefficient based on considering the trials as phases and calculate the significance as a percentage over the whole phases.
- Release velocity the velocity at the moment of release
- Height of release z value of the hammer head or the handle at the moment release.
- Angle of release Arctan was used to calculate the angle at release instance from the length of the opposite side (z) and the length of the adjacent side(y) at the moment of release.
- The radius of curvature calculated by Simi 3D motion Program based on the next equation

$$r = \frac{v^3}{|a \times v|} \qquad \text{-------------------12}$$

- Angular velocity calculated by using the radius of curvature and the tangential velocity.

$$\omega = \frac{v}{r} \qquad \text{-------------------13}$$

- Length of acceleration pathThe length of the acceleration path is the distance the ball travels as it i s increasing in acceleration until the point in the turn where acceleration begins to decrease.

# 5 Results

## 5.1 Results of Kinetic Energy

### 5.1.1 The relationship between each of BSKE and both of the BKE and HHKE.

#### *5.1.1.1 The correlation coefficients between the HKE and each of BKE and HHKE*

**First thrower H (Figure 27)**; **for the *entry*** the relation with BKE was significant at p< 0.01 and 0.05 except for H3 was nonsignificant. The correlation was negative except in H1. The relation in the entry with HHKE was either nonsignificant such in H3 and H5 or significant negative in H1 and H4. ***For the LP-HP***, the relation with BKE had no specific tendency except in the last turn in all trials where it was significant, positive and strong. The relation with the HHKE was for all trials negative and significant. ***For the HP-LP***, the correlation between the HKE and BKE was mostly significant negative especially in H1 and H5, with exception in the other trials. The correlation with HHKE also was significant positive in all trials. ***About duration LP-R**,* the correlation with BKE was significant positive, while it was negative with HHKE, furthermore the best trial, which had the weaker degree in the correlation.

**Second thrower K (Figure 28)**; **for the *entry*** the correlation between HKE and BKE was significant positive strong, and the best trials was the smaller correlation value. The relation in the entry with HHKE was in K3 and K6 significant at p<0.01 negative and in K2 nonsignificant. ***About the durations of LP-HP***, the correlation with BKE was not the same among the trials or the durations in the same trial. There were minimum 2 or three durations in the trials positive strong and significant at p<0.01, and the last turn was one of them, unlike the relation with the HHKE, since it was for all trials negative and significant at p<0.01, except a duration in each of K3 and K6 that was non significant. ***About the durations HP-LP***, the correlation between the HKE and BKE was significant at p<0.01 negative in K3 and K6, but in K2 the durations were not the same and the last was significant at p<0.01 positive. The correlation with HHKE also was significant at p<0.01 positive in all trials. ***About duration LP-R**,* the correlation with BKE was significant at p<0.01 positive, while it was negative correlation with HHKE:

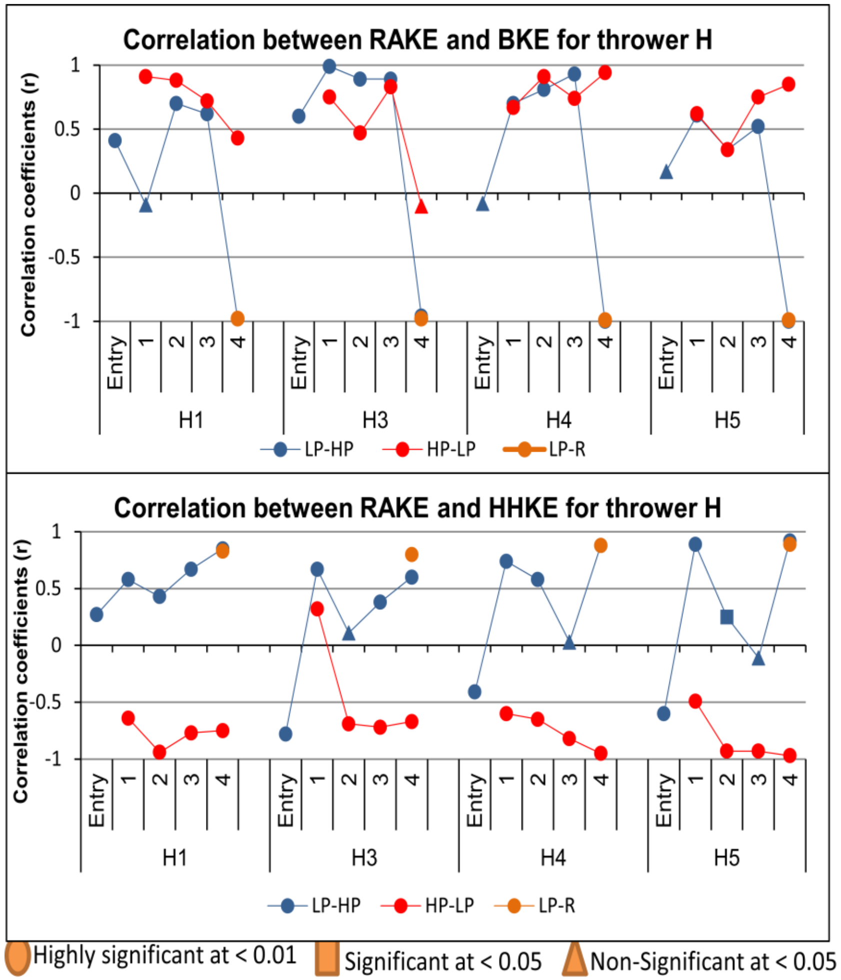



Figure 27. The linear correlation coefficients between RAKE with each of BKE and HHKE through LP-HP, HP-LP and Release phases for thrower H

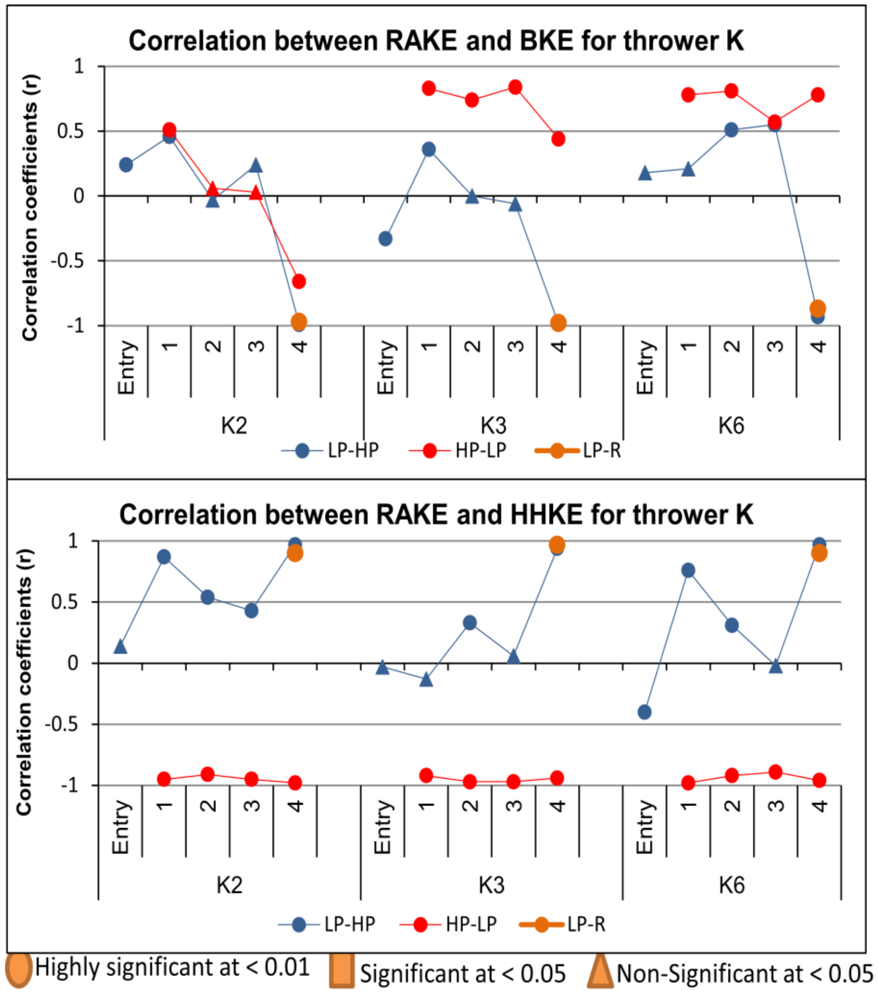



Figure 28. The linear correlation coefficients between RAKE with each of BKE and HHKE through LP-HP, HP-LP and Release phases for thrower K

#### *5.1.1.2 Correlation coefficients between the UTOKE and each of BKE and HHKE*

**First thrower H (Figure 29)**; ***for the entry*** the relation with BKE was significant except for H1, and was negative in H3 and H5, while it was positive in H4. The relation with HHKE was nonsignificant, except H1, which was significant at p<0.01 negative. ***For the LP-HP***, the relation with BKE had no specific tendency except in the last turn in all trials where it was positive strong and significant at p<0.01. Unlike the relation with the HHKE, since it was for all trials negative and significant at p<0.01,except the second duration in H5 was none significant. ***For the HP-LP***, the correlation between the UTOKE and BKE had no special tendency even in the last duration in the trials. The correlation with HHKE had mostly significant positive attitude, except the last two phases in H3 and H4, as well as the second duration in H1. ***About duration LP-R****,* the correlation with BKE was significant at p<0.01 positive, while it was negative correlation with HHKE.

**Second thrower K (Figure 30)**; for the ***entry*** the correlation between UTOKE and BKE was significant at p<0.01 in the trials, except K3, where K2 negative and K3 positive. The relation in the entry with HHKE was in K3 and K6 significant at p<0.01 negative and in K2 nonsignificant. ***About the durations of LP-HP***, the correlation with BKE only in K3 positive and significant at p< 0.01, but in the other trials' durations varies, they only agreed in the last duration, which was positive significant and strong. On the other hand, the correlation with the HHKE for all trials was negative and significant at p<0.01, except a duration in K6. ***About the durations HP-LP***, the correlation between the UTOKE and BKE was significant negative in K3, the other trials' durations were not the same. The correlation with HHKE also was significant positive in all trials especially in K3, with exception of duration in each of the other trials. ***About duration LP-R****,* the correlation with BKE was significant at p<0.01 positive, while UTOKE correlated negatively with HHKE, with a notice that K2 has the smallest value of correlation with both of BKE and HHKE.

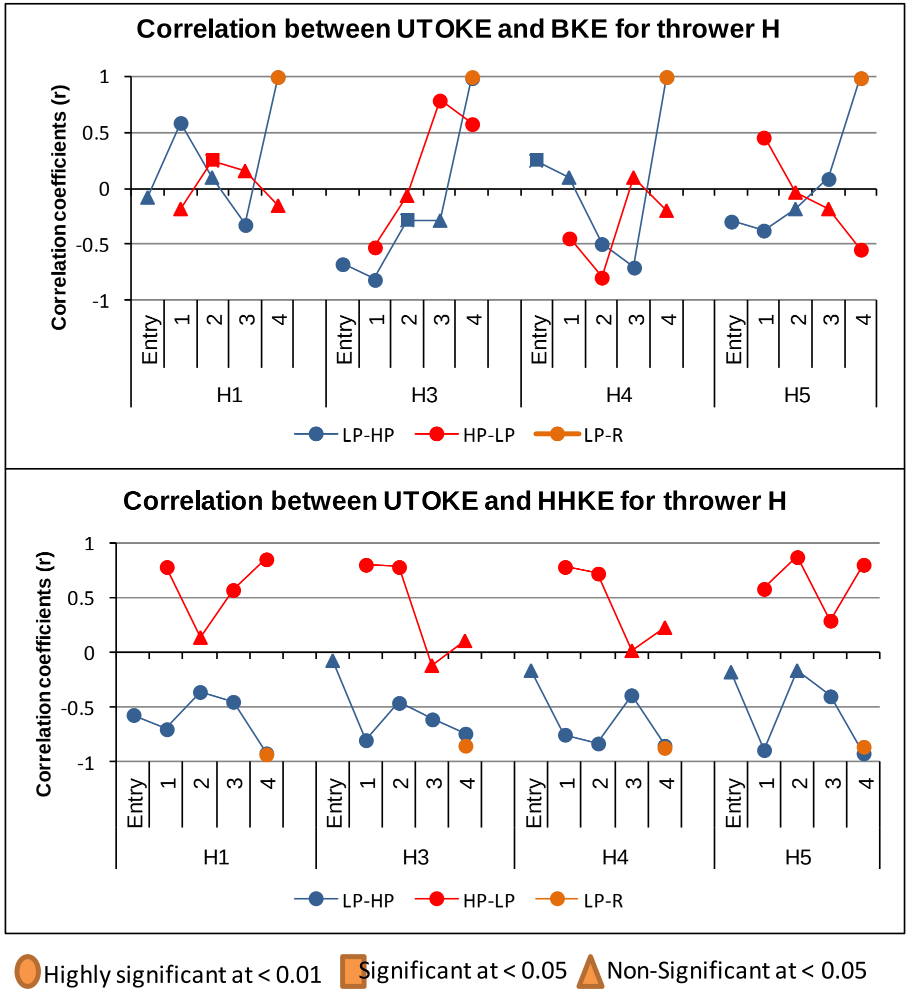



Figure 29. The linear correlation coefficients between UTOKE with each of BKE and HHKE through the LP-HP, HP-LP and Release phases for thrower H , Where 1, 2, 3 and 4 refer to the turn number, add to entry and release phase

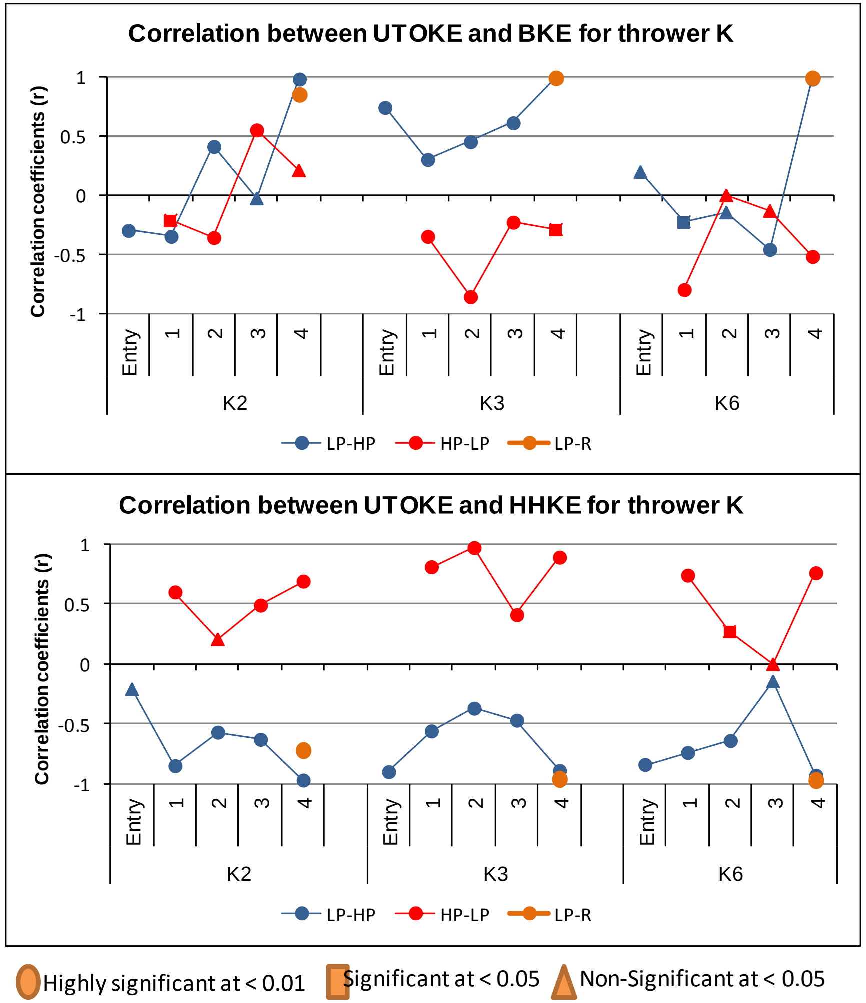



Figure 30. The linear correlation coefficients between UTOKE with each of BKE and HHKE through the LP-HP, HP-LP and Release phases for thrower K, where 1, 2, 3 and 4 refer to the turn number, add to entry and release phase

### *5.1.1.3 Correlation coefficients between the LTOKE and each of BKE and HHKE*

**First thrower H (Figure 31)**; for the ***entry*** the relation with BKE was positive significant at p<0.01. The relation in the entry with HHKE was significant at p<0.01 negative except in H4. ***About the durations of LP-HP***, in each trial one or two duration were found non significantly correlated with BKE, but the rest in H1 and H5 positive, while in H3 and H4 only the final duration which was positive. On the other hand, the relation with the HHKE was for all trials negative and significant at p<0.01 and p<0.05. ***About the durations HP-LP***, the correlation between the LTOKE and BKE had no special attitude in H1 and H3, but in H5 and last three durations in H4 were significantly positively correlated. The correlation with HHKE presented a nonsignificant correlation in H4 except last duration, and two durations in H5 added to one in H3. The trials agreed together in the negativity and significantly correlation of the last duration with exception of H5. ***About duration LP-R,*** the correlation with BKE was significant at p<0.01 positive and H4 with perfect correlation, while it was negative correlation with HHKE. It was noticed that H4 was the smallest value among the trials.

**Second thrower K (see Figure 32)**; for the ***entry*** the correlation between LTOKE and BKE was significant at p<0.01 and positive and K2 was the smallest value. The relation in the entry with HHKE was significant at p<0.01 negative. ***About the durations of LP-HP***, the correlation with BKE was positive and significant at p<0.01, except one or two durations in K2 and K6. On the other hand, the correlation with the HHKE for all trials was negative and significant at p<0.01. ***About the durations HP-LP***, the correlation between the LTOKE and BKE illustrated the agreement between K2 and K3 in the positivity significantly (at p<0.01) relationship only in the last two durations. The correlation with HHKE was also significant at p<0.01 and p<0.05 positive in K2 and K3, with exception of one duration in K2. ***About duration LP-R,*** the correlation with BKE was significant at p<0.01 positive, while it was negative correlation with HHKE.

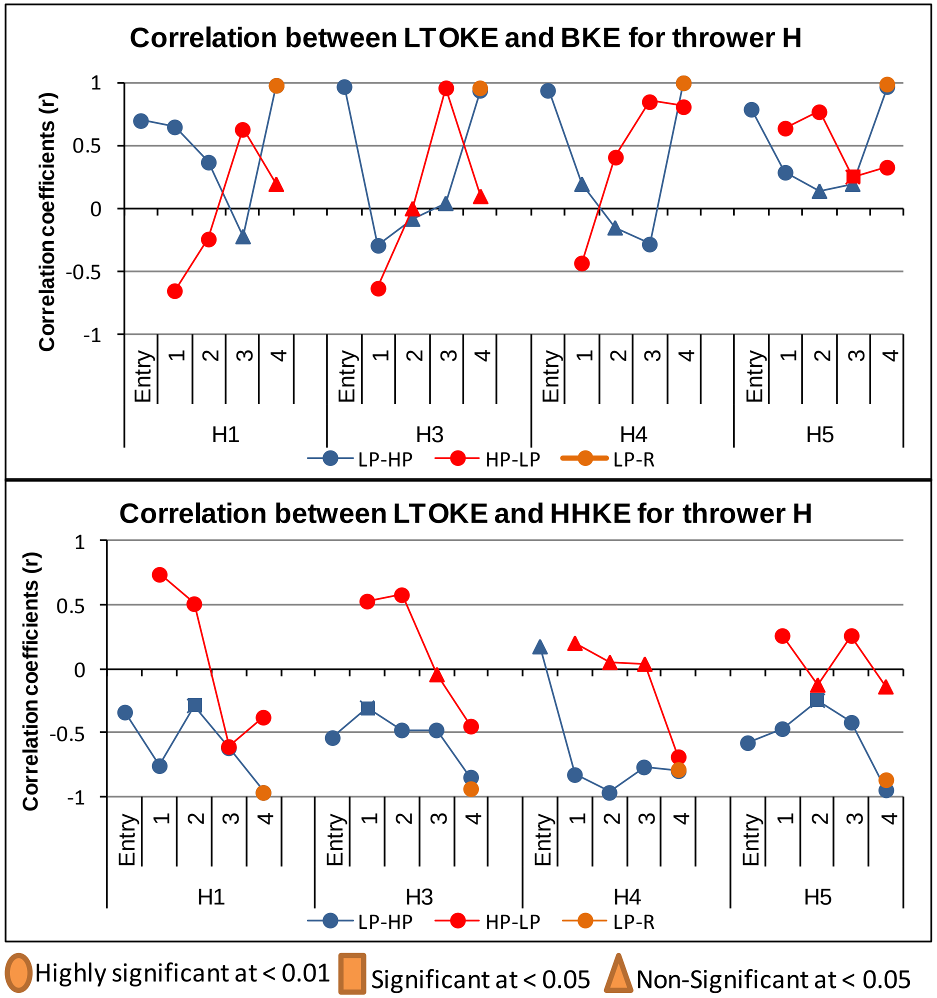



Figure 31. The linear correlation coefficients between LTOKE with each of BKE and HHKE through the LP-HP, HP-LP and Release phases for thrower K
Where 1, 2, 3 and 4 refer to the turn number, add to entry and release phase

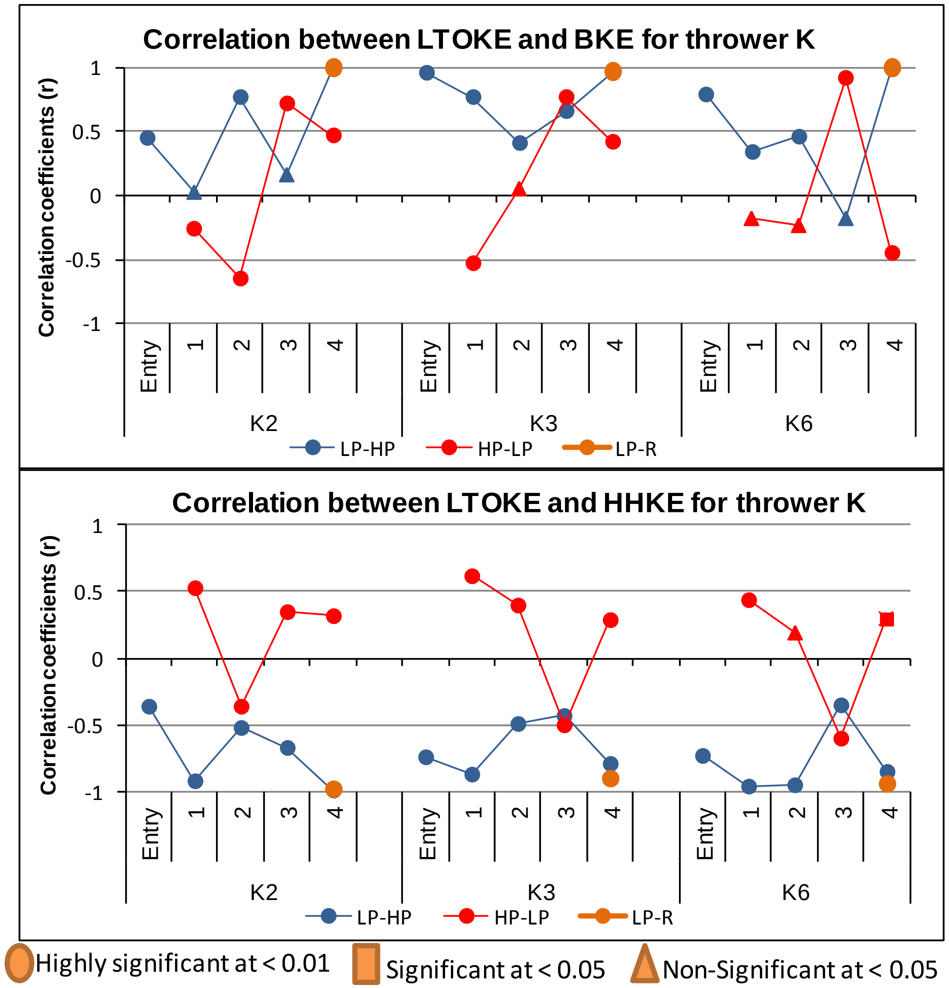



Figure 32. The linear correlation coefficients between LTOKE with each of BKE and HHKE through the LP-HP, HP-LP and Release phases for thrower H
Where 1, 2, 3 and 4 refer to the turn number, add to entry and release phase

#### *5.1.1.4 Correlation coefficients between the RAKE and each of BKE and HHKE*

**First thrower H (Figure 33)**; for the ***entry,*** the relation with BKE was significant at $p< 0.01$ positive in H1 and H2, while nonsignificant with the others. The correlation with HHKE was significant at $p<0.01$ negative except in H1. ***For the LP-HP***, the first three durations in each trial, except in H1 were observed significantly positively correlated with BKE, while the last duration was negative. On the other hand, the relation with the HHKE was for all trials positive and significant at $p<0.01$ and $p<0.05$, except one duration in each trial. ***For the HP-LP***, the correlation between the RAKE and BKE was significant positive except last duration in H3. The correlation with HHKE presented a significant negative correlation, except first duration in H3. ***About duration LP-R,*** the correlation with BKE was negatively significant at $p<0.01$, while it was positive correlation with HHKE.

**Second thrower K (Figure 34)**; for the ***entry,*** the correlation between RAKE and BKE showed variation from trial to trial. The relation in the entry between RAKE with HHKE was significant at $p<0.01$ negative only in K6. ***About the durations of LP-HP***, K2 and K3 agreed in the negativity of the last duration as K6 and the nonsignificance of the first duration, as well as the positivity of the middle durations. The correlation with the HHKE for all trials was positive and significant, except one or two durations in K3 and K6. ***About the durations HP-LP***, the correlation between the RAKE and BKE illustrated the agreement between K3 and K6 in the positive significant ($p<0.01$) correlation. The correlation with HHKE in all trials was negative significant at $p<0.01$. ***About duration LP-R,*** the correlation with BKE was negative significant at $p<0.01$, while it was positive correlation with HHKE.

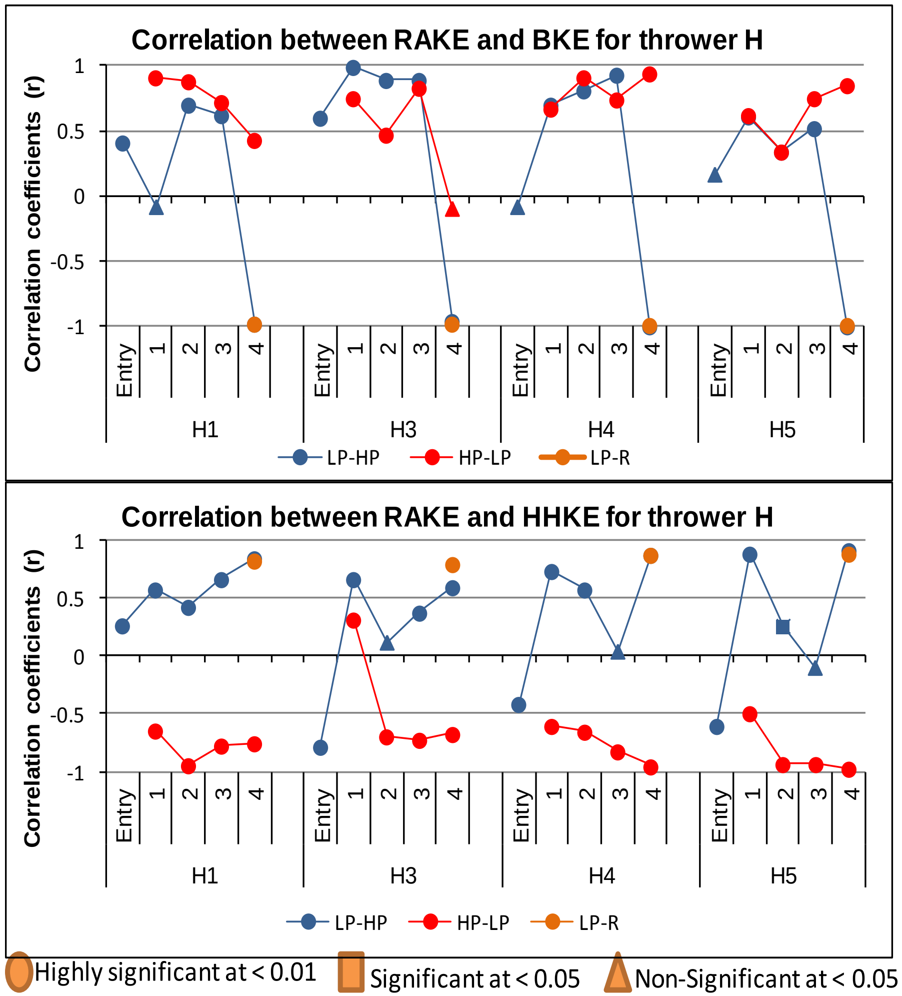



Figure 33. The linear correlation coefficients between RAKE with each of BKE and HHKE through LP-HP, HP-LP and Release phases for thrower H

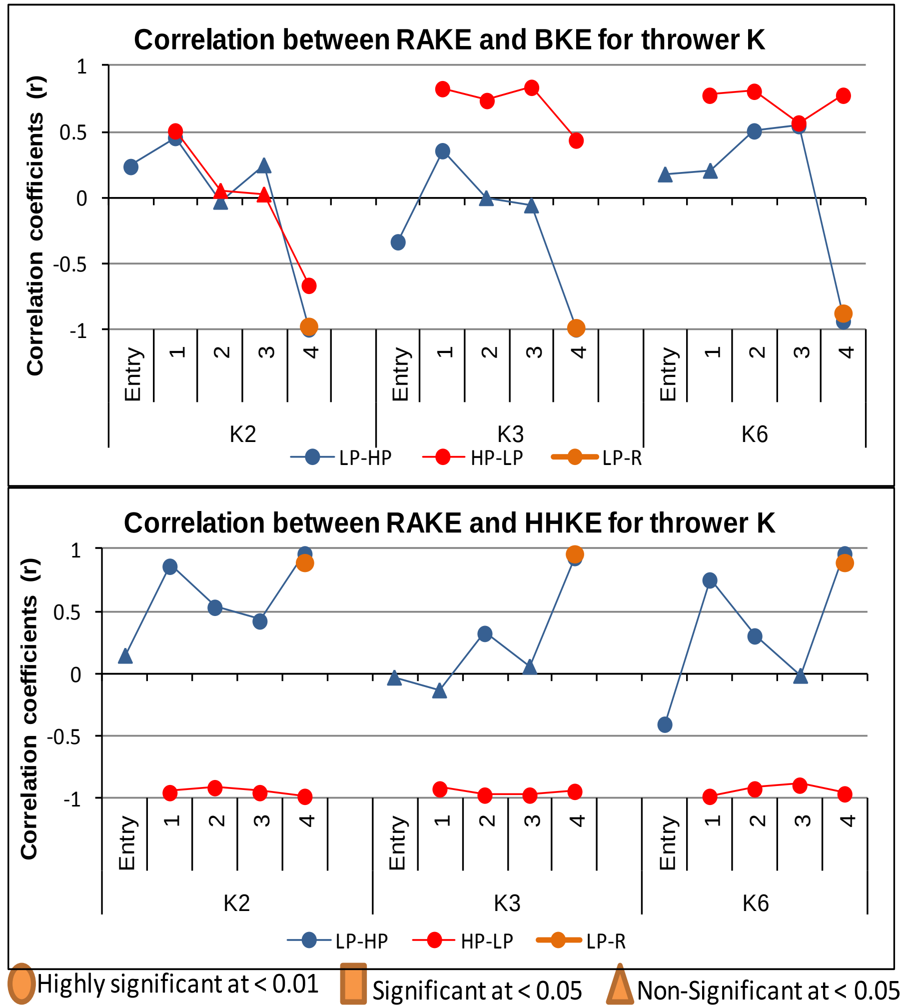



Figure 34. The linear correlation coefficients between RAKE with each of BKE and HHKE through LP-HP, HP-LP and Release phases for thrower K

#### *5.1.1.5 Correlation coefficients between the LAKE and each of BKE and HHKE*

**First thrower H (Figure 35)**; for the ***entry,*** the relation with BKE was significant at $p< 0.01$ negative in al trials. The relation in the entry with HHKE was not the same and H4 non significant. ***About the durations of LP-HP***, the first three duration in each trial were observed significantly negatively correlated with BKE, except in H3, and the last duration was positive. On the other hand, the relation with the HHKE agreed in the trials in the negativity and significance of the last duration. In addition, H4 had the first three durations positive. ***About the durations HP-LP***, the correlation between the LAKE and BKE was significant negative in all trials except the first duration in H1 and H5, regarding that H3 was different. The correlation with HHKE presented a significant positive correlation. ***About duration LP-R**,* the correlation with BKE was positive significant at $p<0.01$, except H3 which was nonsignificant. It was negative correlation with HHKE in all tirals except H3.

**Second thrower K (Figure 36)**; for the ***entry,*** the correlation between LAKE and BKE was negative significant at $p<0.01$. The relation in the entry with HHKE was nonsignificant for all trials. ***About the durations of LP-HP***, in all trials the correlation between LAKE and BKE was negative significant at $p<0.01$, except in the last duration. The correlation with the HHKE for all trials varied unless mentioning the last duration, which was negatively correlated, also except H3. ***About the durations HP-LP***, except H3, the correlation between the LAKE and BKE could be illustrated as a negative significant correlation. The correlation with HHKE in all trials was positive significant at $p<0.01$. ***About duration LP-R**,* the correlation with BKE was significant at $p<0.01$ positive, while it was negative correlation with HHKE. It could be noticed that K2 had the smallest value in both correlations.

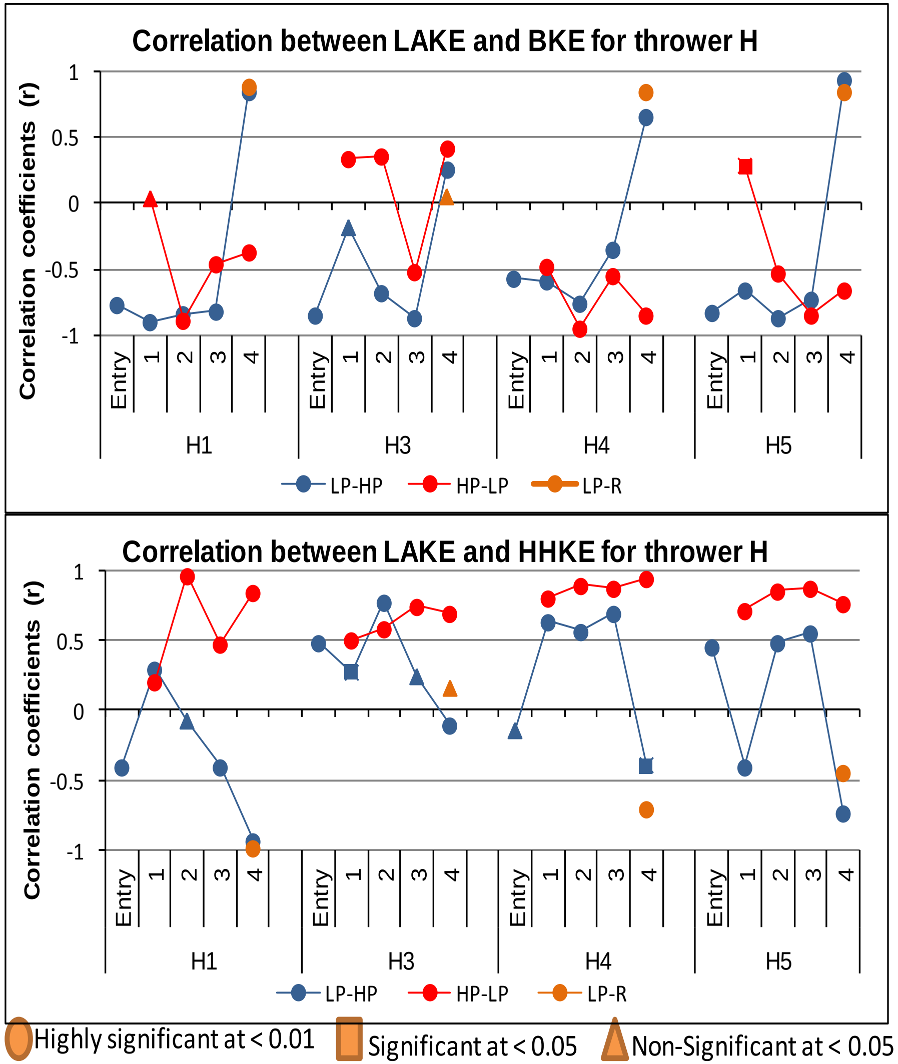



Figure 35.The linear correlation coefficients between LAKE with each of BKE and HHKE through LP-HP, HP-LP and Release phases for thrower H

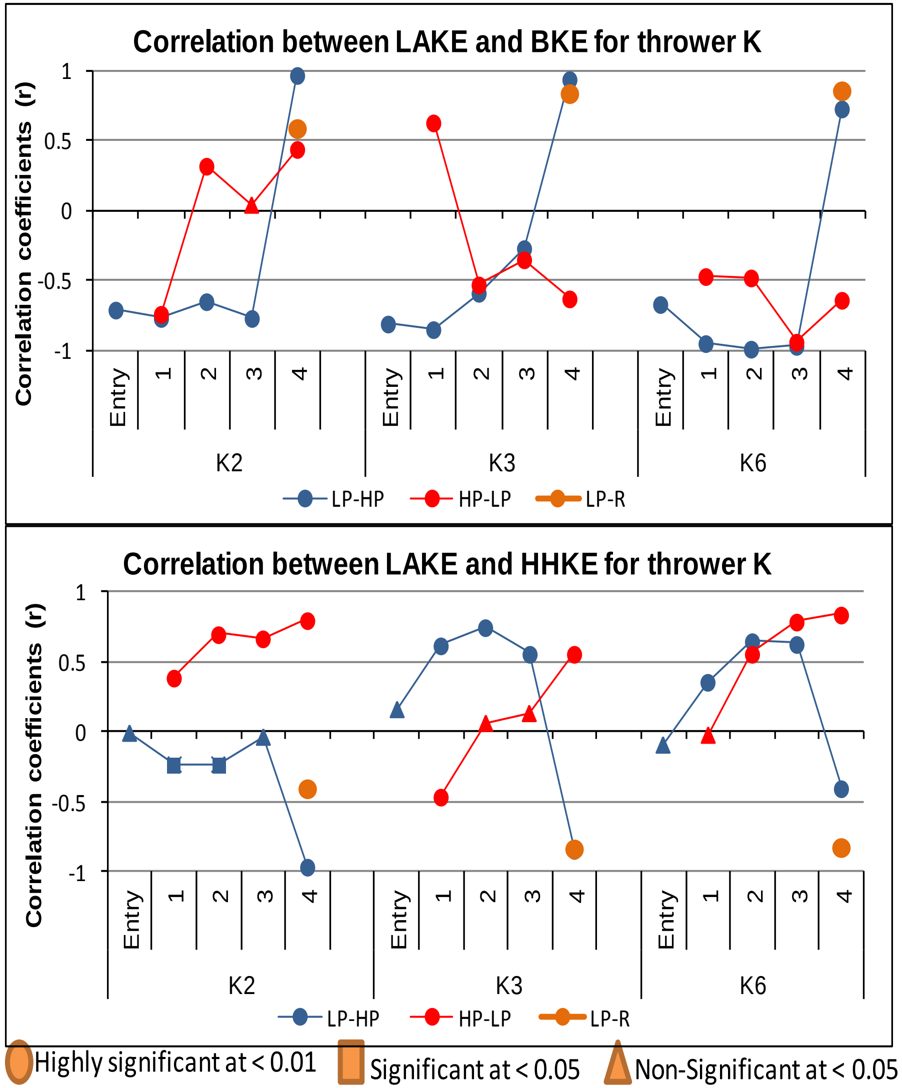



Figure 36. The linear correlation coefficients between LAKE with each of BKE and HHKE Through LP-HP, HP-LP and Release phases for thrower K

#### *5.1.1.6 Correlation coefficients between the RLKE and each of BKE and HHKE*

**First thrower H (Figure 37)**; for the ***entry,*** the relation with BKE was significant positive strong in all trials. The relation in the entry with HHKE was only in H1 nonsignificant. Regarding to the other trials, durations of H3 and H5 were negative while of H4 were positive, the strength of the correlation was not strong as with BKE. ***For the LP-HP***, a significant positive correlation was observed in all trials with BKE. On the other hand, the relation with the HHKE varied, the agreement was in the positivity of first duration, except in H1, as well as the negativity of the last duration, except in H3. ***For the HP-LP***, the correlation between the RLKE and BKE was significant at p<0.01 positive except the last duration in H3, while it was also significant but negative correlation with HHKE in all trials. ***For the LP-R,*** the correlation with BKE was significant at p<0.01 positive, except H3 which was nonsignificant. While it was negative correlation with HHKE, also except H3, since it was positive.

**Secondly thrower K (Figure 38)**; ***for the entry*** the correlation between RLKE and BKE was positive significant at p<0.01 in K2 and K6 stronger than K3. The relation in the entry with HHKE was nonsignificant but in K6. ***For LP-HP***, in all trials the correlation between RLKE and BKE was positive significant at p<0.01, except one duration in K3. On the other hand, K3 and K6 mostly showed negative significant correlation with the HHKE. In K2 only the last duration is negative. ***For the HP-LP***, K3 and K6 showed positive significant correlation between the RLKE and BKE, which gradually get stronger in K6 than in K3. The durations in K2 varied. Regarding to the correlation with HHKE, all trials correlated negatively significantly at p<0.01. ***About duration LP-R,*** except in K2 which was nonsignificant, the correlation with BKE was significant at p<0.01 positive, while it was negative with HHKE.

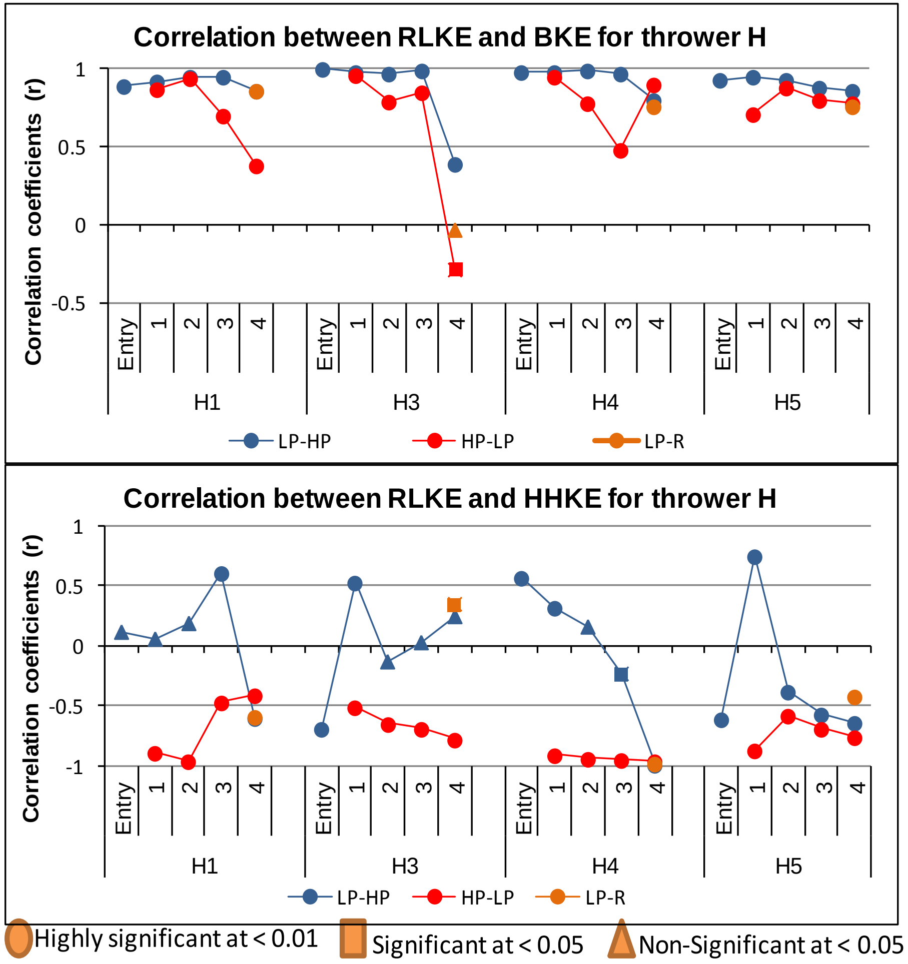



Figure 37. The linear correlation coefficients between RLKE with each of BKE and HHKE through the LP-HP, HP-LP and Release phases for thrower H.

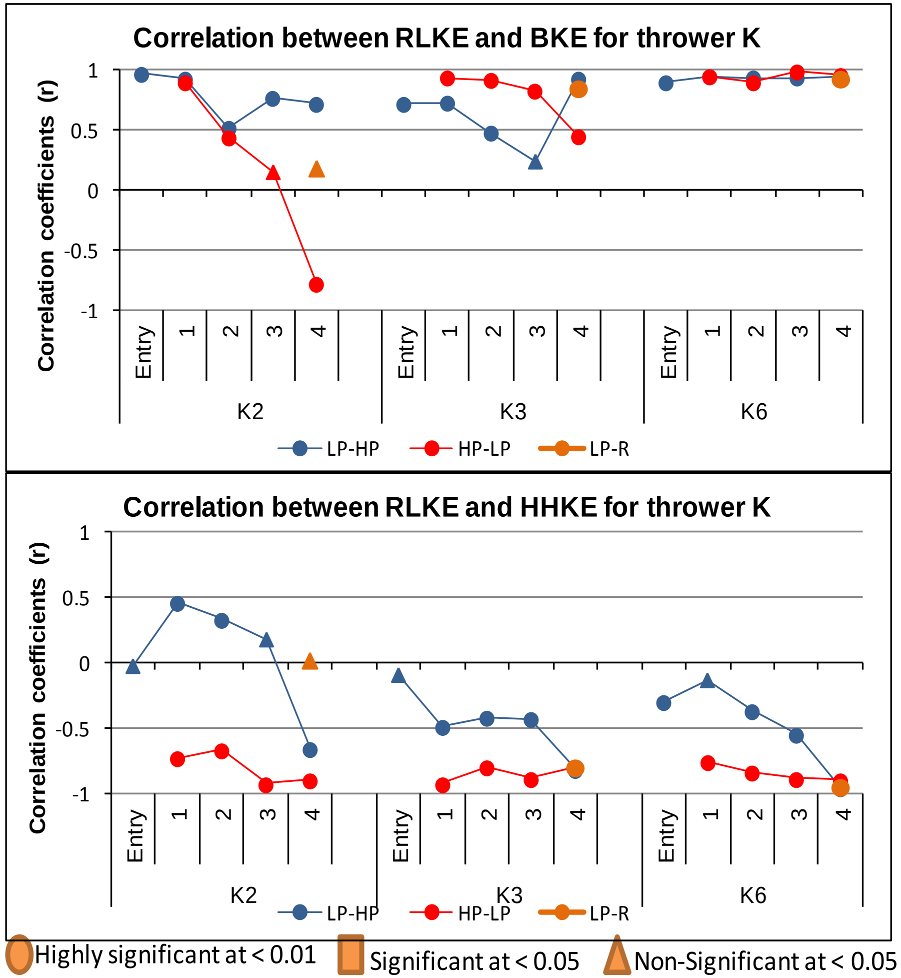



Figure 38. . The linear correlation coefficients between RLKE with each of BKE and HHKE through the LP-HP, HP-LP and Release phases for thrower K

#### *5.1.1.7 Correlation coefficients between the LLKE and each of BKE and HHKE.*

**First thrower H (Figure 39)**; for the ***entry,*** the relation with BKE was significant positive in all trials. The correlation with HHKE in the entry was negatively significant, except H3 where it was nonsignificant. ***For the LP-HP***, a significant positive correlation with BKE was observed in the last duration in all trials, unlike the first three duration, which was negative. On the other hand, the relation with the HHKE varied also among the duration of trial itself, the agreement was in the negativity of last duration, otherwise both of H3 and H4 had two nonsignificant duration against one in H1. ***For the HP-LP***, the correlation between the LLKE and BKE illustrated significance, except two duration in each of H3 and H4, as well as duration in H1. In H5 only the first was positive, H1 and H3 were alike, and the rest durations were negative. While the correlation with HHKE in all trials was significance, except the first duration in H3, and positive. ***For the LP-R,*** the correlation with BKE was strong significance at $p<0.01$ and positive. And it was negative correlation with HHKE.

**Second thrower K (Figure 40)**; for the ***entry*** the correlation between LLKE and BKE was positive significant in K3 and K6 strong, and negative significant in K2. The relation in the entry with HHKE was nonsignificant in K2, negative significant in K3 and K6. ***For the LP-HP***, the trials agreed in that the last phase correlation was positive significant. The rest durations in K2 and K3 were negative, unlike the case in K6. On the other hand, the first three durations in K3 and K6 showed positive significant correlation with the HHKE. But the last duration in all trials was negative. ***For the HP-LP***, after excepting the non significant durations in each trial, the rest durations were negative but the last duration in each of them. Regarding to the correlation with HHKE, all trials correlated positively significantly at $p<0.01$, except one in K3. ***For the LP-R,*** the correlation with BKE was significant positive. while it was negative with HHKE.

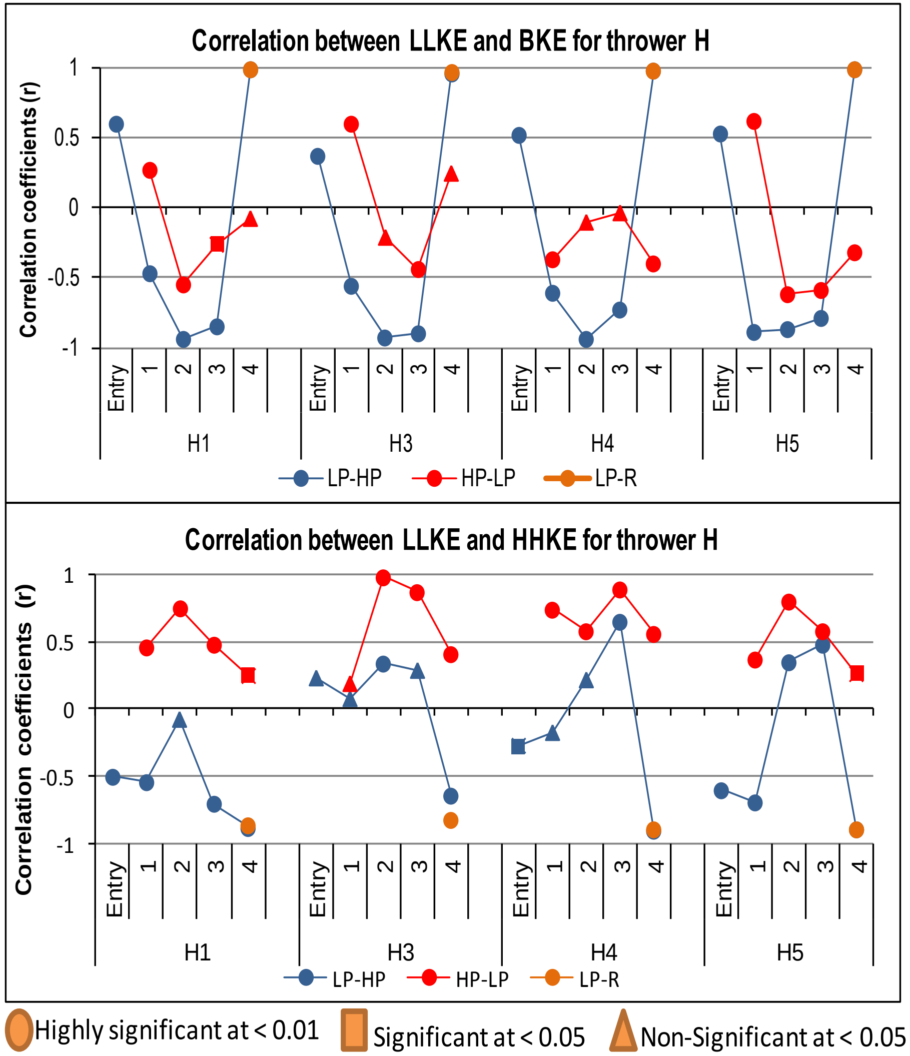



Figure 39. The linear correlation coefficients between LLKE with each of BKE and HHKE through the LP-HP, HP-LP and Release phases for thrower H

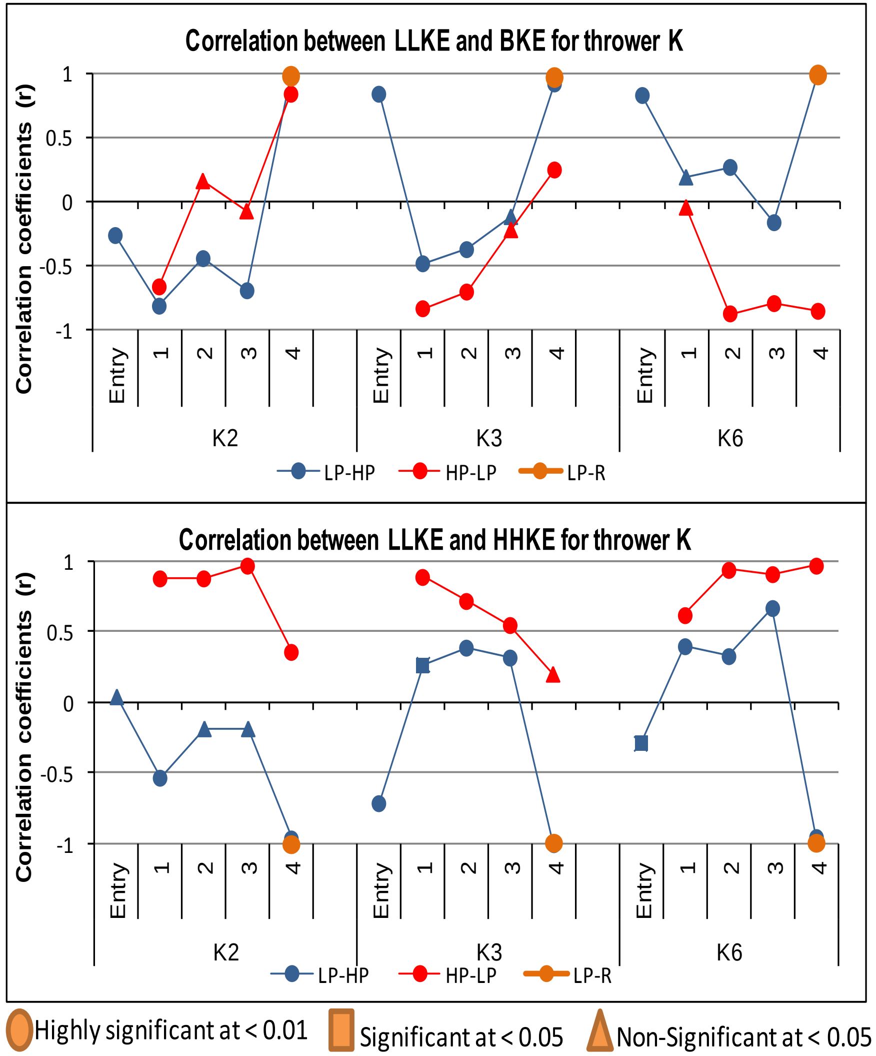



Figure 40. The linear correlation coefficients between LLKE with each of BKE and HHKE through the LP-HP, HP-LP and Release phases for thrower K

### 5.1.2 The relationship between (BKE) and (HHKE).

**First thrower H (Figure 41);** for the ***entry,*** the correlation was significant at p<0.01 in all trials except H1, furthermore it was positive only in H4. ***About the durations of LP-HP***, the trials varied. ***About the durations HP-LP***, the correlation shows significance at p<0.01 and p<0.05, and nonsignificance in some phases in all trials except H5. They agreed in that the last duration was negative. ***About duration LP-R***, the correlation was significant at p<0.01 negative.

**Second thrower K (Figure 41)**; for the ***entry*** the correlation was negative significant at p<0.01, except in K2. ***About the durations of LP-HP***, the correlation was negative significant at p<0.01 and p<0.05.***About the durations HP-LP***, the correlation was negative significant at p<0.01 in K3 and K6, unlike K2 which had no specific tendency. ***About duration LP-R***, the correlation was negative significant at p<0.01.

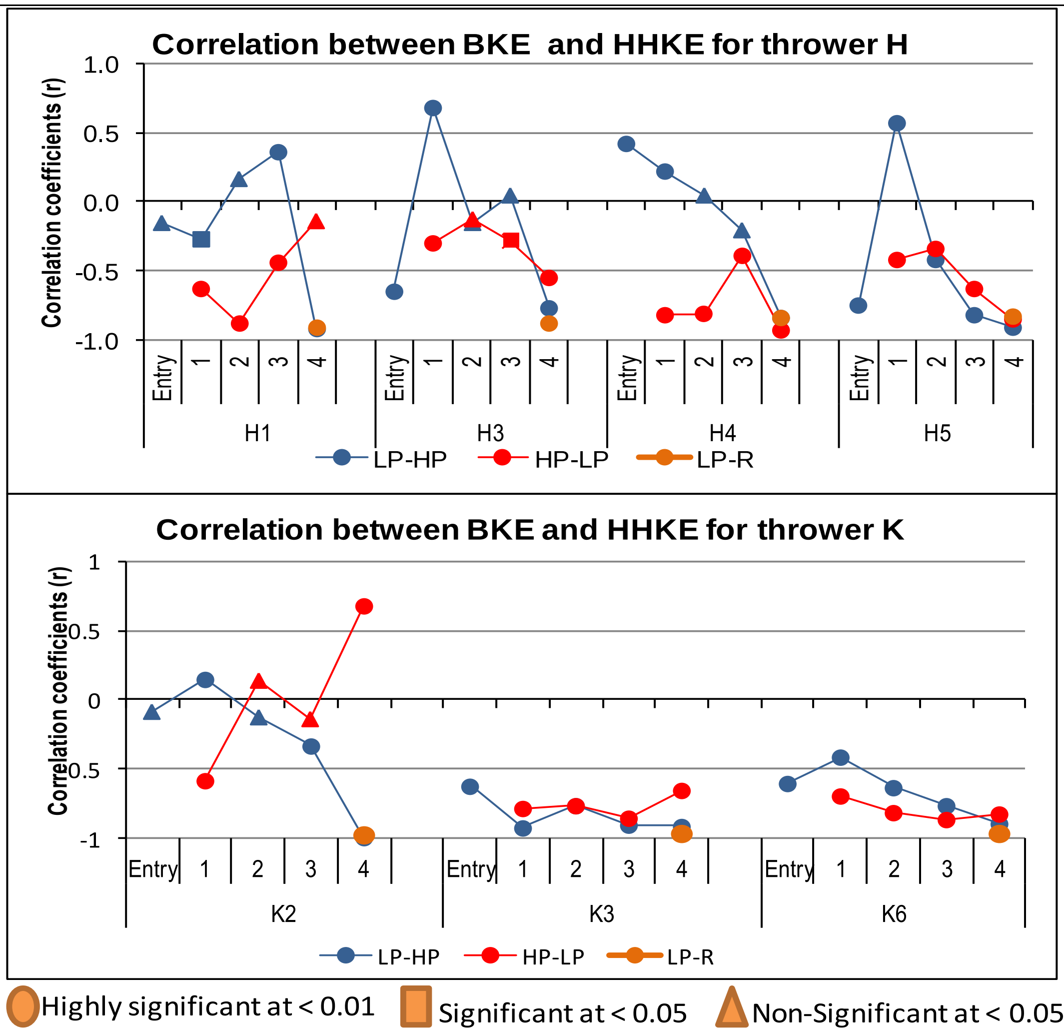



Figure 41. The linear correlation coefficients between BKE and HHKE through the LP-HP, HP-LP and Release phases for both throwers

### 5.1.3 The contribution of the BSKE to the HHKE.

This section of the result would present the descending order of each of BSKE percentages to HHKE during the LP-HP, HP-LP and release ($LP_4$-R) phases in the turnsfor both throwers.

#### *5.1.3.1 The BSKE contribution percentages to HHKE of H1*

Figure (42) shows the segment's contribution percentages in hammer head kinetic energy during the LP-HP, HP-LP, and LP-R for thrower H1. ***For the entry and the first three LP-HP phases***, the descending order of the segments' kinetic energies from the first to the seventh were; respectively, RL (6.6 - 19%), LL ( 4.1 - 5.3%), RA ( 2.4 - 3%), LA ( 1.7 - 2.7%) except in the 1st turn, LTO (2.1 - 2.4%) except in the 1st turn, UTO (0.4 - 0.6%), then Head (0.2 - 0.5%).

***For HP-LP phases***, the descending order was somehow different; whereas LL (6 - 6.8%), LA (1.8 - 2.2%) except in the 3rd turn, RA (1.9 - 2%) except in the 3rd turn, UTO (1 - 1.6%), Head (0.7 - 1.4%) in the first, fourth, fifth, sixth and seventh ranks; respectively. Both of LTO and RL occupied the second and the third ranks alternately. As a conclusion the order was LL, (RL and LTO), LA, RA, UTO then head.

***In the LP4-R phase***, the overall range was between (2.9 - 0.9%) for a descending order as following: (LL and LA), RA, LTO, UTO, Head, and RL.

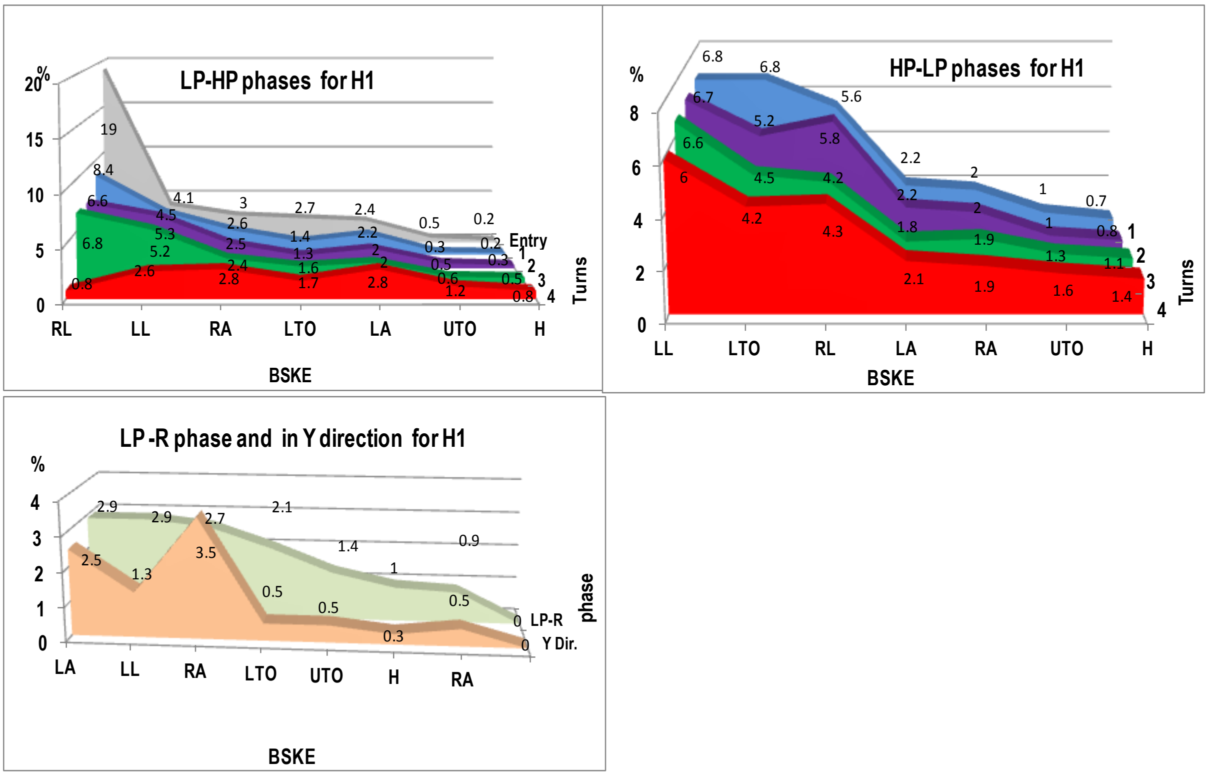



Figure 42. The BSKE contribution percentages to HHKE of H1

### *5.1.3.2 The BSKE contribution percentages to HHKE of H3*

***For the entry and the first three LP-HP phases***; RL (6.2 - 15.57%), LL (3.8 - 7.4%), LA ( 2.6 - 3.2%), RA (2.5 - 2.9%), LTO (1.5 - 2.6%), UTO (0.5 - 0.7%), Head (0.1 - 0.5%), were in the seven ranks respectively.

***For HP-LP phases***, the descending order from the first to the seventh rank was as following: LL ( 6.7 - 8.1%) except in the 1st turn, LTO (5.92 - 7.5%) except in the 2nd turn, RA (2.1 - 2.4%), LA (2.2 - 2.4%), UTO (0.7 - 1.6%) and Head (0.5 - 1.6%); respectively. except the third rank which was for the RL (5.5 - 10.8%) in the last two turns and for LL and LTO in the first two turns. As a conclusion the order was LL, (RL and LTO), RA, LA, UTO then H.

***For release phase ($LP_4$-R)***, the overall range was (4.1 - 1.1%) and the final order was LA, LL, RA, LTO, RL, H and UTO.

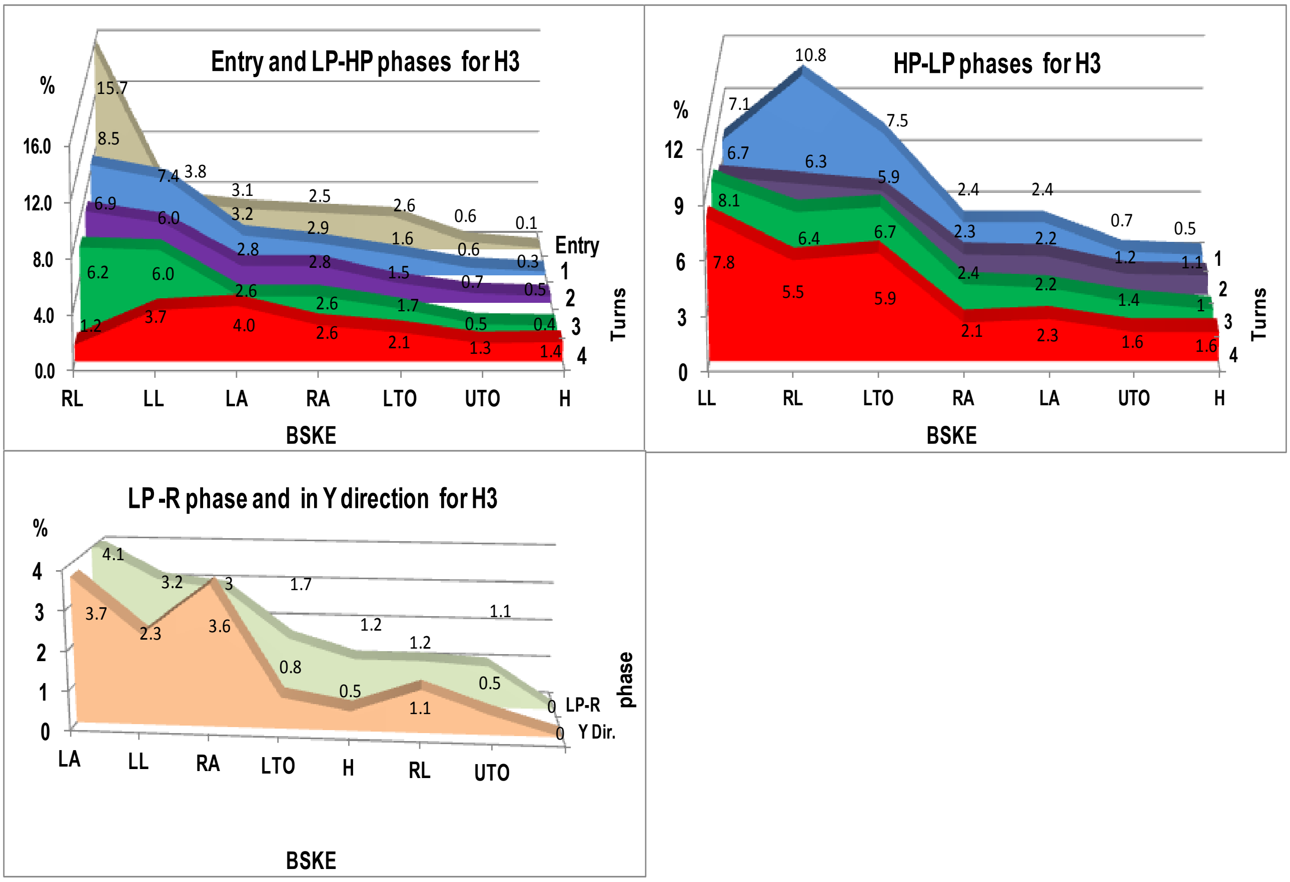



Figure 43. The BSKE contribution percentages to HHKE of H3

### *5.1.3.3 The BSKE contribution percentages to HHKE of H4*

***For the entry and the first three LP-HP phases***, the descending order of the seven ranks were occupied by RL (6.9 – 17.8%), LL (4 – 5.9%), LA (2.5 – 3%), RA (2.4 – 2.9%), LTO (1.6 – 2.4 %), UTO (0.6 -0.7%) , finally H (0.1 – 0.6%), respectively (Figure 44).

***For HP-LP phases***, RL (5.5 – 7%) occupied the first rank in the 1st and 2nd turns, and then moved back in the 3rd and 4th turns to occupy the third rank. LTO (5.4 – 6.8%) came in the second place in all phases except the second turn. For LL (6.3 – 7.3%) occupied the first rank in the 3rd and 4th turns but before one time as the third and once as the second. The last four places were for LA (2.3, 2.5%), RA (2, 2.1%), UTO (1, 1.7%), finally H (0.6 – 1.7%) respectively.

***For LP₄-R phase*** the order were LL, LA, RA, LTO, H, UTO then RL in rang between (0.8 – 2.7%).

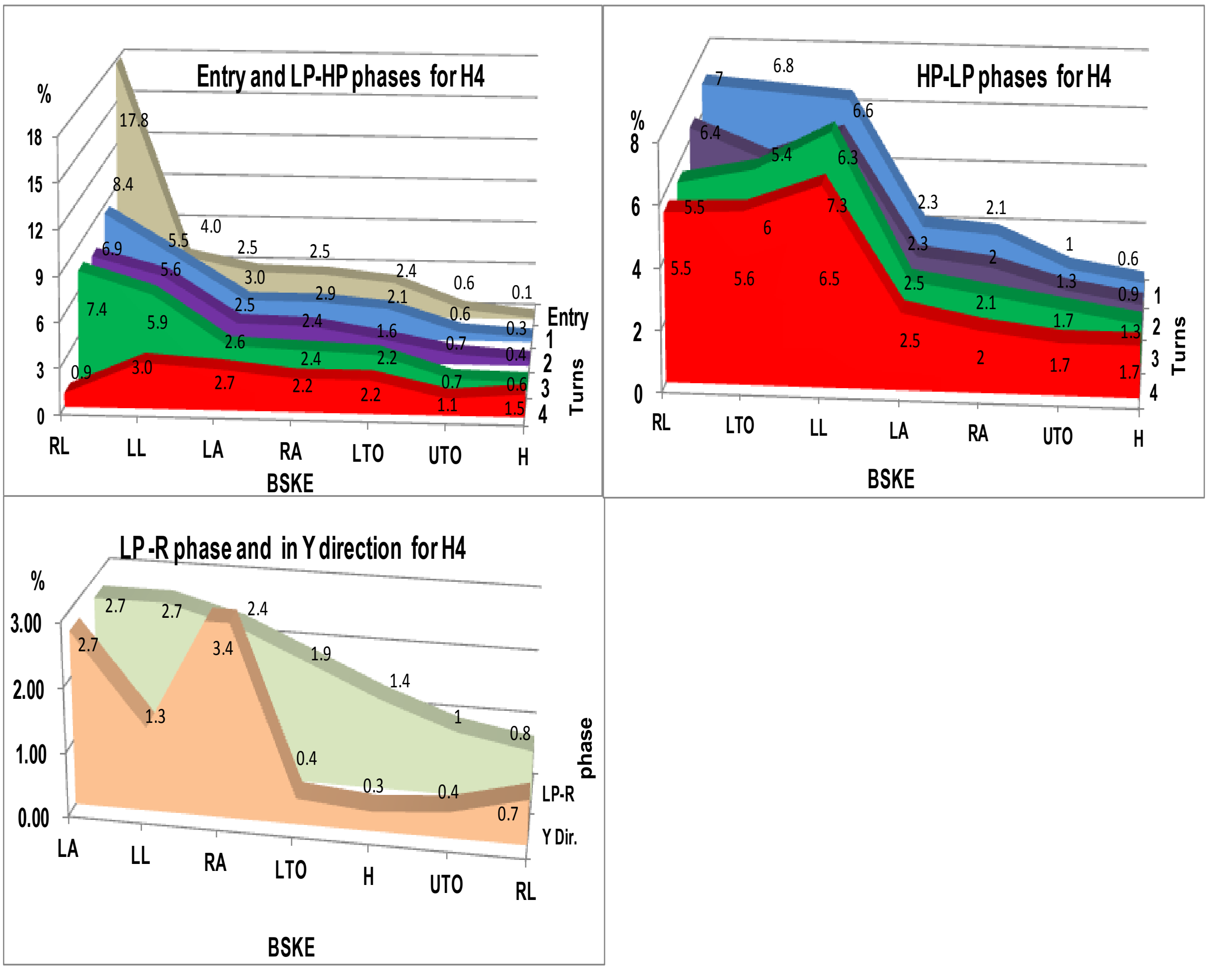



Figure 44. The BSKE contribution percentages to HHKE of H4

#### *5.1.3.4 The BSKE contribution percentages to HHKE of H5*

***For the entry and the first three LP-HP phases***, the descending order of the seven ranks were occupied by RL (6 – 16.2%), LL (4.1 – 5.9%), RA (2.4 – 2.9%), LA (2.3 – 2.8%), LTO (1.7 – 2.9 %), UTO (0.5 -0.6%), finally H (0.2 – 0.5%), respectively. However, there were some exceptions in the 1st turn where the order changed to be LTO, RA, then LA for the middle three places, as well as LL was first in the 4th turns instead of RL (Figure 45).

***For HP-LP phases***, LL (6 – 7.7%), UTO (0.7 - 1.7%) and H (0.7 – 1.5%) occupied the first, sixth and seventh ranks. In the third rank came LTO (5.7 – 6.5%) in the 1st and 2nd turns, and then moved forward in the 3rd and 4th turns to occupy the second rank, via verse for RL (5.7- 6.4%) which came in the second place in 2nd turn then moved backward to the third rank after that. The fourth and fifth places were for LA (2 - 2.6%), RA (2.1 - 2.3%) alternately, but even there were no real different between the kinetic energy percentages of both of them, the reason we can put them in the same rank .

***For LP$_4$-R phase***, the order were RA, LA, LL, LTO, UTO, RL, then H in rang between (0.9 – 3.2%) (Figure 45).

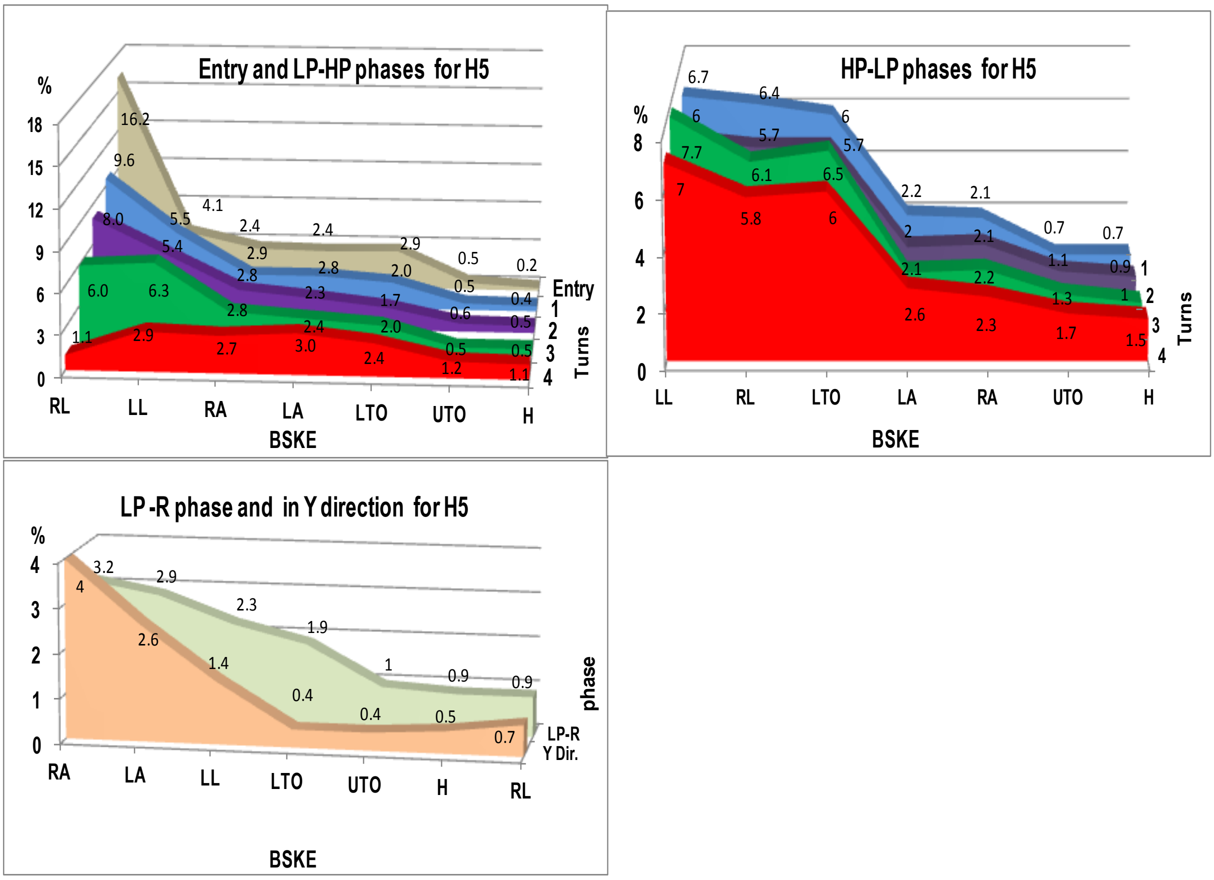



Figure 45. The BSKE contribution percentages to HHKE of H5

#### *5.1.3.5 The BSKE contribution percentages to HHKE of K2*

***For the entry and the first three LP-HP phases***, the descending order changed from turn to the other, but basically RL (5 – 9.6%) and LL (3.7 – 5.2%) were the first and second, as well the UTO (0.6 – 1.1%) was the sixth then the seventh. RA (2 – 2.5%) and LA (1.5 – 2%) achieved the third and fourth contribution percentages in the first three turns. H (0.4 – 2.4%) and LTO (1.3 – 1.9 %) step forward from turn to the next to be in the second and third rank, because their contribution increased. Therefore, the RA and LA fall to the fourth and the fifth (Figure 46).

***For HP-LP phases***, LL (5.6 – 6.2%) had the first and the second ranks, LTO (2.8 – 5.3%) was the second except in the 2nd turn, and RL (2.2- 6.5%) was third except in the 1st turn. RA (1.6- 2.3%) and LA (1.5 – 1.9%) were in the middle of contribution order then fall from turn to another to the last of the list. That was as a result of increasing the percentage of the H (1.5 – 6.6%) which due to stepping forward from the end of the order at the beginning to be the first of the order at the last turn.

***For LP$_4$ – R***, the descending order was H, LA, RA, LL, UTO, LTO, and RL in range (0.3 – 3.4%). It was important to mention that the contribution of Head increased from turn to the next to be in the first rank at the last phase (Figure 46).

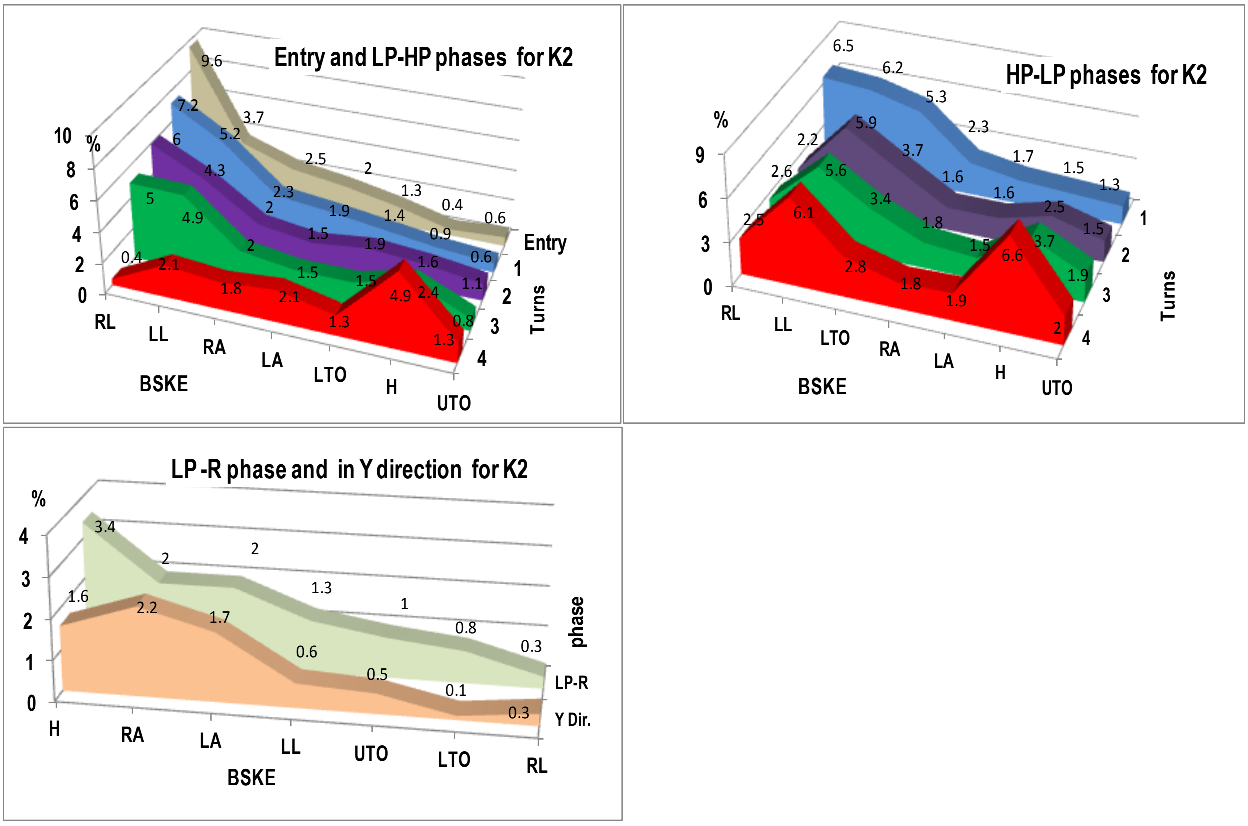



Figure 46. The BSKE contribution percentages to HHKE of K2

#### *5.1.3.6 The BSKE contribution percentages to HHKE of K3*

***For the entry and the first three LP-HP phases***, the descending order changed from turn to the other but basically RL (4.8 – 13.7%), LL (3.5 – 4.3%) , RA (2.2 – 2.8%) except in the 4th turn, as well the UTO (0.6 – 1.1%) were the first, second, third and seventh; respectively. The contribution of H (0.7 – 2.6%) increased continuously, which lead the H to achieve forward steps over the phases to be the third in the 4th turn. LTO (1.5 – 2.1 %) and LA (1.6 – 1.7%) occupied the ranks between the fourth and the sixth alternately (Figure 47).

***For HP-LP phases***, a systematic attitude of the contributions percentages over the most of ranks was observed, with exceptions. Therefor, the order generally was like the following: LL (4.9 – 6.4%) except in the 4th turn, RL (2.5- 3.9%) except in the 3rd turn, RA (1.9- 2.2%) except in the 1st turn, LA (1.5 – 1.8%) except in the 1st turn, and UTO (1.1 – 1.6%) occupied the first, third, fifth, sixth and seventh ranks; respectively. LTO (2.3 - 4.4%) was between the second and the fourth ranks, while the H (1.7 – 5.3%) was in progress over the turns to present the highest contribution at the last turn .

***For $LP_4$ – R phase***, the descending order was H, LA, RA, LL, LTO, UTO, and RL in range ( 0.4 – 3.3%). It's important to mention that the contribution of H increased from turn to the next to be in the first rank at the last turn (Figure 47).

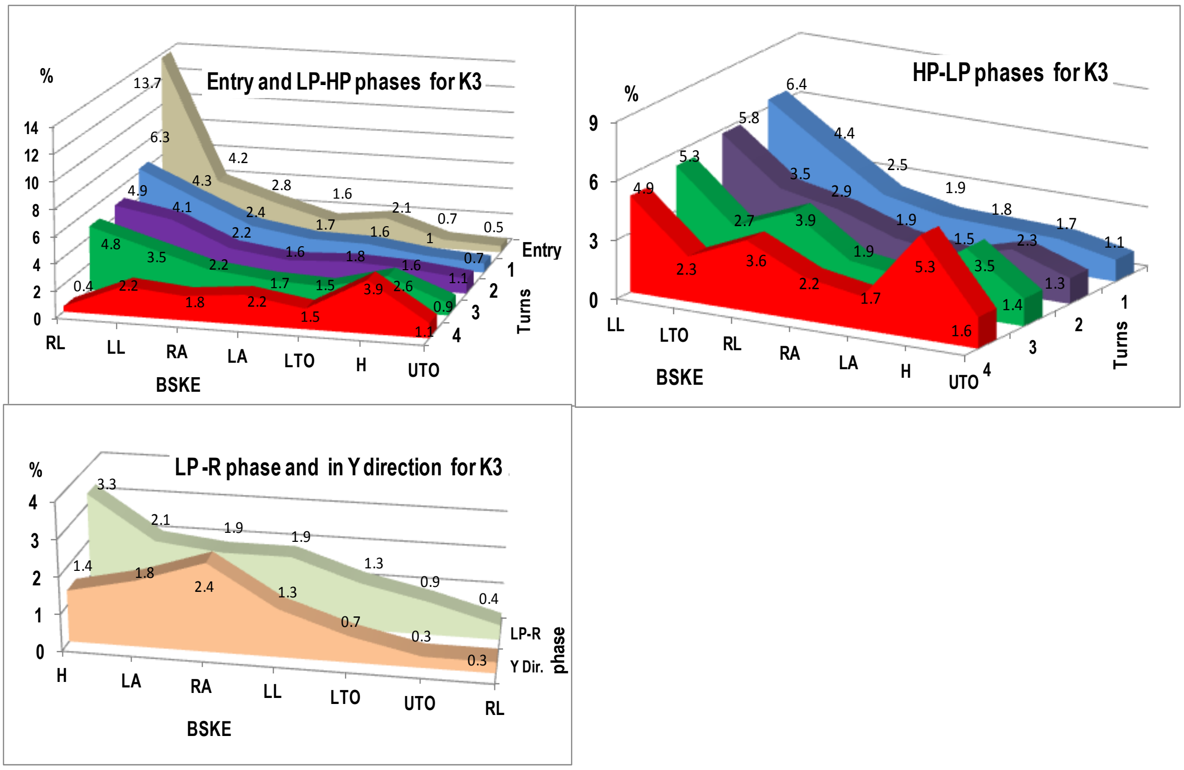



Figure 47. The BSKE contribution percentages **to HHKE of K3**

#### *5.1.3.7 The BSKE contribution percentages HHKE of K6*

The descending order of the BSKE percentages to the HHKE was presented in (Figure 48).

***For the entry and the three LP-HP phases***, showed that, the descending order was changed from turn to another. Generally, the RL (5.6 – 12.6%), RA (2.2 – 3%) except in the 4th turn, LTO (1.9 – 2.3 %), and UTO (0.6 – 1.1%) were the first, second, third and seventh; respectively. The contribution of H (0.6 – 2.4%) increased continuously, and moved forward steps over the turns to be the second in the 4th turn. LL (1.3 – 2.1%), and LA (1.6 – 1.8%) occupied the ranks between the fourth and the sixth alternately (Figure 48).

***For HP-LP phases***, A systematic attitude of the contributions percentages over the most of ranks was observed, but with exceptions. Therefore, the ranges of the contribution percentages was like the following: H (1.6 – 6.3%), UTO (1.3 – 2%), LTO (3.1 – 5.1%), RA (1.7 - 2.2%), LA (1.8 – 1.9%), RL (2.4 – 5.3%), LL (1.4 – 2.2%) (Figure 48).

***For LP4- R phase***, the descending order was H, LA, RA, LTO, UTO, LL, and RL in range (0.4 – 3.7%). It was important to mention that the contribution of H increased from turn to the next to be in the first rank at the last turn (Figure 48).

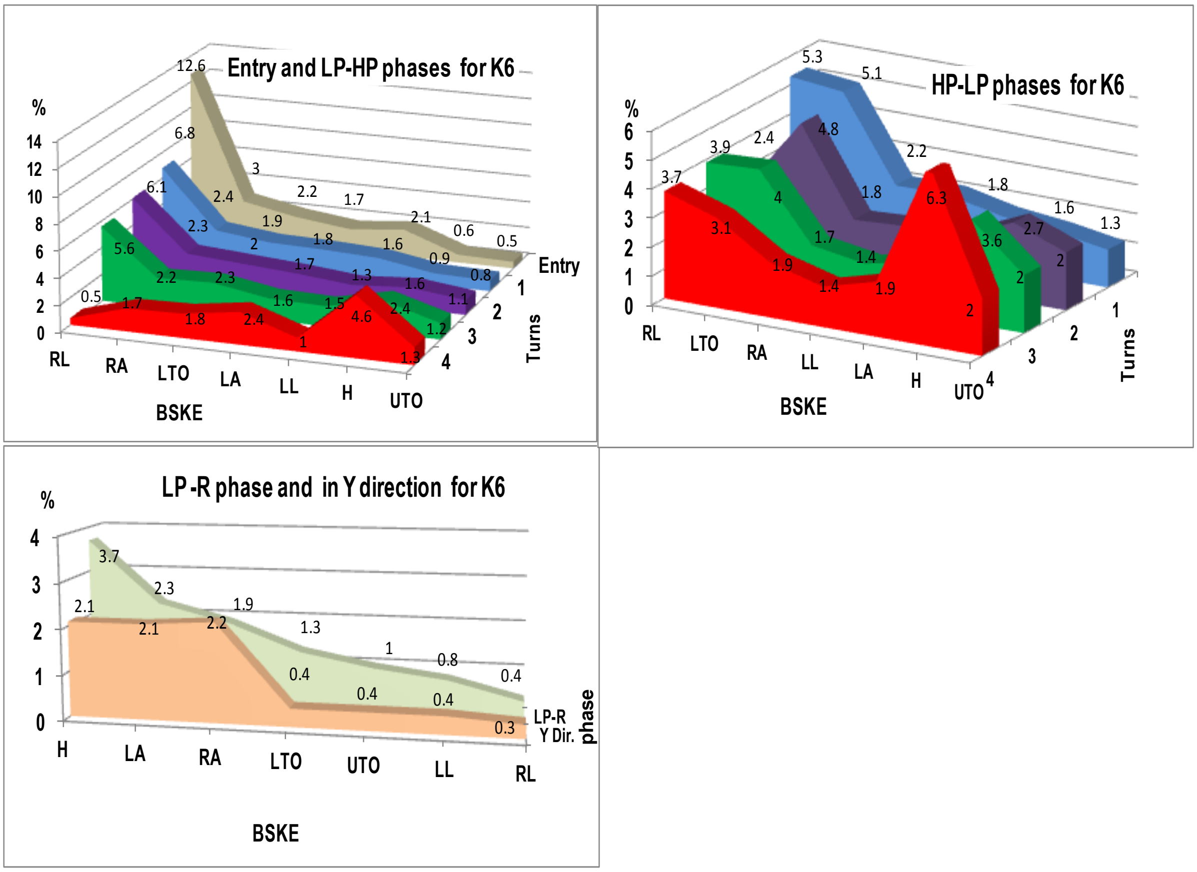



Figure 48. The BSKE contribution percentages to HHKE of K6

### 5.1.4 The contribution of the BKE to the HHKE

Figures (49 and 50) show the contribution percentages of the BKE to the HHKE over mentioned phases in this study for throwers H and K. With regard to thrower H, the maximum values were observed in the first turns in each trial. Furthermore, the last turn had the lowest contribution values over all phases in each trial, since the values of the last phases over all trials of H.

***For the entry and the first three LP-HP phases*** were 12.8, 16.6, 13.6 and 14.5% comparing to the averages of the previous phases 22.4, 23.5, 23.7, and 23.6% of the trials H1, H3, H4 and H5 respectively. ***In HP-LP phases*** the percentages order were 17.8, 21.4, 19.6 and 19.6%, of H1, H3, H4 and H5 respectively.

Regarding to thrower K, as well as H trials, the maximum values were observed also in the first turn of the accelerations in each individual trial, while the last turn had the lowest contribution values over all turns in each trial, since the values of the last turns over all trials ***in LP-HP phases*** were 13.9, 13 and 13.2% comparing to the averages of the previous phases 19.1, 19.5 and 18% of the trials K2, K3 and K6 respectively. ***In Release phase*** were 17.3, 16.1 and 15.5%, of K2, K3 and K6 respectively

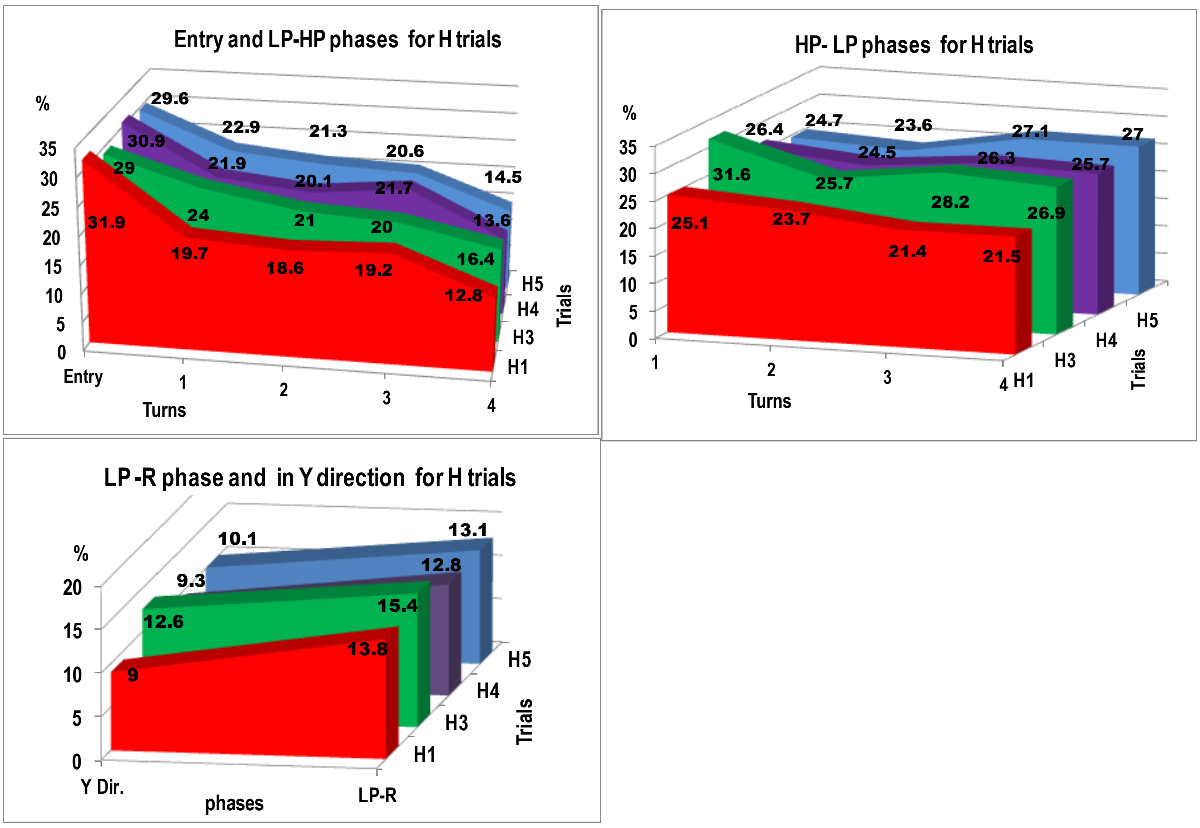



Figure 49. The BKE contribution percentages to HHKE during the LP-HP, HP-LP and Release ($LP_4$-R) phases all trials of throwers H

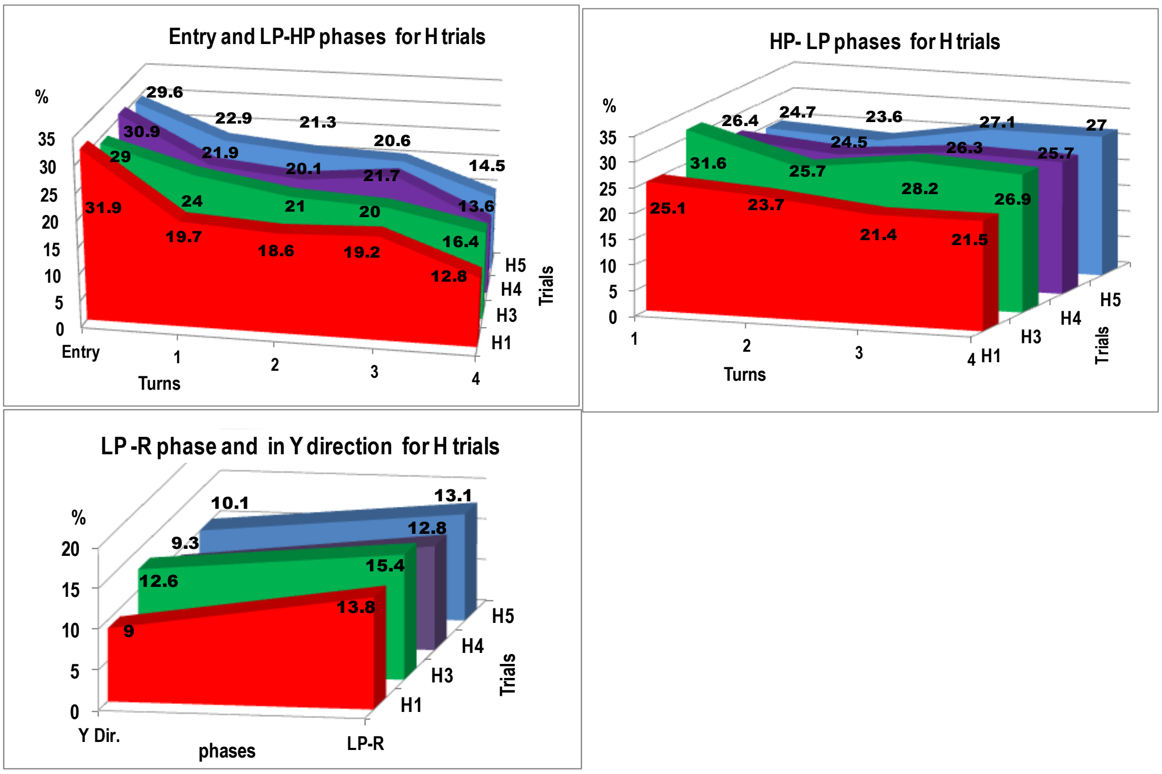



Figure 50. The BKE contribution percentages to HHKE during the LP-HP, HP-LP and Release ($LP_4$-R) phases for all trials of throwers K

### 5.1.5 Simple and Stepwise regression analysis at release phase

In order to detect the relationships between the total body kinetic energy and body segments kinetic energy to the hammer head kinetic energy, the simple and stepwise regression analysis were computed, respectively by using SPSS software.

#### *5.1.5.1 The Stepwise regression between BSKE and HHKE at release phase for thrower H.*

***For thrower H trials***, table (9) shows the analysis of variance of stepwise regression and some descriptive regression statistics for the relationship between BSKE and HHKE during the release phase ($LP_4$-R).

***Overall trials of thrower H***, the stepwise regression analysis has revealed a highly significant relationship between BSKE and HHKE at $p<0.001$ (Table 9). The mean square of the regressions over all H trials was very high comparing to MS of the error indicating that the strong relationship between BSKE and HHKE. The number of the body segments that resulted from the stepwise regression analysis was more in trials H1 and H3 than in H4 and H5.

Table 9. Analysis of variance and descriptive statistics of stepwise regression for BSKE to HHKE for thrower H trials.

| Trial | Phase | Model | DF | MS | F | Sign. < |
|---|---|---|---|---|---|---|
| H1 | LP4-R | Regression | 6 | 15893.67 | 111550.7 | 0.001 |
| | | Residual | 29 | 0.14 | | |
| H3 | LP4-R | Regression | 6 | 38984.31 | 19093.91 | 0.001 |
| | | Residual | 38 | 2.04 | | |
| H4 | LP4-R | Regression | 2 | 60450.74 | 14947.88 | 0.001 |
| | | Residual | 32 | 4.04 | | |
| H5 | LP4-R | Regression | 5 | 18074.7 | 4456.9 | 0.001 |
| | | Residual | 39 | 4.1 | | |

### 5.1.6 Stepwise regression model of BSKE to HHKE at release phase for thrower H.

#### *5.1.6.1 Stepwise regression of BSKE and HHKE for thrower H1*

Form Release Phase $LP_4$- R of the trial H1, table (10) shows the stepwise regression model was highly significant and the constant was positive. Six body segments were involved in this model, four segments (LTO, RA, Head and UTO) were associated negatively with the HHKE and displayed $R^2$ ranged between 84.6 and 98% of the variance. While the segments LA and RL were correlated positively with HHKE and explained $R^2$ 93.4 and 73.2% from the variability of the HHKE, respectively. Based on the $R^2$ values, the most affected segment on the HHKE in this phase was RA and displayed 98% of the variance. The stepwise regression analysis has excluded LL segment from the model. Therefore, the final regression model of this phase can be summarized as following:

$$HHKE_{LP4\text{-}R} = 1336.1 + ( - 6.5\ LTO - 10.5\ RA - 12.3\ Head - 4.5\ UTO) + 9.5\ LA + 3.3\ RL$$

In conclusion of this trial, RA has been observed to be the most important segment in the rotation direction that affects the HHKE, since it explained the highest $R^2$ values in both acceleration and deceleration phases.

Table 10. Stepwise regression model of the body segments to the hammer head kinetic energy (HHKE) for the release phase H, trial 1

| Dir. | Last model | Coef. | SE | t value | Sign. < | Pa. r | R2 |
|---|---|---|---|---|---|---|---|
| LP4-R | Constant | 1336.12 | 15.95 | 83.75 | 0.001 | - | - |
| | LA | 9.54 | 0.47 | 20.29 | 0.001 | 0.967 | 0.934 |
| | LTO | -6.45 | 0.33 | -19.77 | 0.001 | -0.965 | 0.931 |
| | RA | -10.49 | 0.28 | -37.29 | 0.001 | -0.990 | 0.980 |
| | Head | -12.29 | 0.96 | -12.78 | 0.001 | -0.922 | 0.849 |
| | UTO | -4.49 | 0.36 | -12.64 | 0.001 | -0.920 | 0.846 |
| | RL | 3.32 | 0.37 | 8.90 | 0.001 | 0.856 | 0.732 |

#### *5.1.6.2 Stepwise regression of BSKE and HHKE for thrower H3*

In general, the stepwise regression models were highly significant at P<0.001, and the constant value was positive see table (11).

In Release phase $LP_4$-R of trial H3, six body segments' kinetic energy were evolved by the analysis in this model, three of them (LTO, RA and UTO) associated with the HHKE negatively with $R^2$ values ranged between 22.5 and 91.8% of the variance. While the other three (LL, LA and RL) correlated with HHKE positively and $R^2$ values were between 31.1 and 94.3% from the variability of the HHKE. $R^2$ values referred to the LL (94.3%) as the most effective kinetic energy value on the HHKE in this phase. The Head was excluded from the model during the stepwise regression analysis. Therefore, HHKE in this phase could be predicted by the equation

$$HHKE_{Lp4\text{-}R} = 1531.7 + 5.4\ LL + 5.4\ LA + 3.8\ RL + (-1.1\ LTO - 36.2\ UTO - 14.8\ RA)$$

Table 11. Stepwise regression model of the body segments to the hammer head kinetic energy (HHKE) for the release phase of H, trial 3.

| Dir. | Last model | Coef. | SE | t value | Sign. < | Pa. R | R2 |
|---|---|---|---|---|---|---|---|
| | Constant | 1531.73 | 41.98 | 36.49 | 0.001 | - | - |
| | LTO | -1.13 | 0.34 | -3.32 | 0.002 | -0.475 | 0.225 |
| | LL | 5.38 | 0.22 | 25.04 | 0.001 | 0.971 | 0.943 |
| **LP4-R** | LA | 5.44 | 0.56 | 9.67 | 0.001 | 0.843 | 0.711 |
| | RL | 3.84 | 0.93 | 4.14 | 0.001 | 0.558 | 0.311 |
| | UTO | -36.22 | 1.76 | -20.56 | 0.001 | -0.958 | 0.918 |
| | RA | -14.84 | 1.03 | -14.46 | 0.001 | -0.920 | 0.846 |

### *5.1.6.3 Stepwise regression of BSKE and HHKE for thrower H4*

In general , the stepwise regression models for H4 were highly significant at $P < 0.001$, and the constant value was positive see table (12).

In Release phase $LP_4$-R of the trial H4, Only RL and LA kinetic energy were selected by the stepwise analysis , both of them correlated with the HHKE negatively, their $R^2$ values represented 99.8 and 96.7% of the variance. Consequently, RLKE was the most effective value on the HHKE in this phase. The rest Kinetic energies for the other segments (H, RA, LL, LTO and UTO) were excluded by the stepwise regression analysis. The final regression model of this phase could be summarized as follow

$$HHKE_{LP4\text{-}R} = 1220.98 + (-14.9\ RL - 2.6\ LA)$$

Table 12. Stepwise regression model of the body segments to the hammer head kinetic energy (HHKE) for the release phase for thrower H, trial 4.

| Dir. | Last model | Coef. | SE | t value | Sign. < | Pa. R | R2 |
|---|---|---|---|---|---|---|---|
| | Constant | 1517.63 | 2.49 | 609.85 | 0.001 | - | - |
| **LP4-R** | RL | -14.93 | 0.12 | -123.96 | 0.001 | -0.999 | 0.998 |
| | LA | -2.64 | 0.09 | -30.59 | 0.001 | -0.983 | 0.967 |

### *5.1.6.4 Stepwise regression of BSKE and HHKE for thrower H5*

In general , the stepwise regression models for H5 were highly significant at $P < 0.001$, and the constant value was positive see table (13).

In Release phase $LP_4$-R of the trial H5, five values were selected during the analysis steps , they were Head, RL, LTO, LL and UTO , two of them correlated with the HHKE negatively (LL and UTO), with represented $R^2$ values 99 and 28% of the variance; respectively. while the other three correlated with HHKE positively, with $R^2$ values in range between 62.8 and 97.6% of variance. Therefore, RLKE was the most effective value on the HHKE in this phase. The stepwise regression analysis excluded RA and LA Kinetic energies. The final model of this phase could be:

$$HHKE_{LP4\text{-}R} = 1232 + 7.5\ H + 9.4\ RL + 3.1\ LTO + (-\ 10.8\ LL - 4.5\ UTO)$$

Table 13. Stepwise regression model of the body segments to the hammer head kinetic energy (HHKE) for the release phase thrower H, trial 5.

| Dir. | Last model | Coef. | SE | t value | Sign. < | Pa. R | R2 |
|---|---|---|---|---|---|---|---|
| LP4-R | Constant | 1232.0 | 1.49 | 829.3 | 0.001 | - | - |
| | Head | 7.5 | 0.47 | 15.8 | 0.001 | 0.930 | 0.865 |
| | RL | 9.4 | 0.24 | 39.8 | 0.001 | 0.988 | 0.976 |
| | LTO | 3.1 | 0.38 | 8.1 | 0.001 | 0.792 | 0.628 |
| | LL | -10.8 | 0.18 | -59.4 | 0.001 | -0.995 | 0.989 |
| | UTO | -4.5 | 1.15 | -3.9 | 0.001 | -0.529 | 0.280 |

### 5.1.7 The relationship between BSKE and HHKE for thrower K.

Table (14) shows the stepwise regression analysis of variance and some descriptive statistics for the relationship between BSKE and HHKE in release phase.

Overall trials of thrower K, the stepwise regression analysis has revealed a highly significant relationship between BSKE and HHKE at $p<0.001$ (Table 14). The mean square (MS) of the regressions over all K trials was very high comparing to MS of the error indicating that the strong relationship between BSKE and HHKE.

Table 14. Analysis of variance and descriptive statistics of stepwise regression for BSKE to HHKE for thrower K trials during release phase

| Trials | phases | | DF | MS | F | Sign. < |
|---|---|---|---|---|---|---|
| K2 | LP4-R | Regression | 4 | 106140.29 | 250696.65 | 0.001 |
| | | Residual | 38 | 0.42 | | |
| K3 | LP4-R | Regression | 5 | 7549.18 | 27276.65 | 0.001 |
| | | Residual | 36 | 0.28 | | |
| K6 | LP4-R | Regression | 3 | 27808.79 | 81702.23 | 0.001 |
| | | Residual | 36 | 0.34 | | |

### 5.1.8 Stepwise regression model (line) of BSKE to HHKE in Release phase for thrower K.

#### *5.1.8.1 Stepwise regression of BSKE and HHKE for thrower K2*

In general, the stepwise regression models were highly significant at $P < 0.001$, and the constant values was positive see table (15).

In Release phase $LP_4$-R of the trial K2, four body segments' kinetic energy were involved by the analysis in this model, LL and Head associated with the HHKE negatively with $R^2$ values were 90.3 and 96.1%; respectively , whereas the LTO and UTO correlated positively with HHKE and $R^2$ values were 74.1 and 84.9%. $R^2$ values referred to the Head as the most effective value on the HHKE in this phase.

The other values of RL, LA, RA were excluded by the model by the stepwise regression analysis. Therefore, HHKE predictor equation

$$HHKE_{LP4\text{-}R} = 1443.3 + 2.7\ LTO + 0.7\ UTO + (-2.2\ LL - 3.9\ Head)$$

Table 15. Stepwise regression model of the body segments to the hammer head kinetic energy (HHKE) for the release phase for thrower K, trial 2

| Dir. | Last model | Coef. | SE | t value | Sign. < | Pa. R | $R^2$ |
|---|---|---|---|---|---|---|---|
| $LP_4$-R | Constant | 1443.27 | 1.82 | 792.57 | 0.001 | - | - |
| | LL | -2.19 | 0.12 | -18.83 | 0.001 | -0.950 | 0.903 |
| | Head | -3.90 | 0.13 | -30.80 | 0.001 | -0.981 | 0.961 |
| | LTO | 2.70 | 0.26 | 10.43 | 0.001 | 0.861 | 0.741 |
| | UTO | 0.67 | 0.05 | 14.61 | 0.001 | 0.921 | 0.849 |

#### *5.1.8.2 Stepwise regression of BSKE and HHKE for thrower K3*

In general, the stepwise regression models of K3 were highly significant at $P<0.001$, and the constant value was positive see table (16).

In Release phase $LP_4$-R of the trial K3, five body segments' kinetic energy were selected by the analysis in this model, LL, RL and LTO correlated with the HHKE negatively, with $R^2$ values ranged between 52.9 and 98%, whereas the RA and UTO correlated positively with HHKE and the $R^2$ values were 88.5 and 95%%; respectively. $R^2$ values revealed that LL as the most effective value on the HHKE in this phase. The other values of LA and Head were excluded by the stepwise regression analysis. Therefore, HHKE predictor equation

$$HHKE_{LP4\text{-}R} = 877.4 + 10.5\ RA + 17.6\ UTO + (-3.6\ LL - 4\ RL - 6.7\ LTO)$$

Table 16. Stepwise regression model of the body segments to the hammer head kinetic energy (HHKE) for the release phase for thrower K, trial 3

| **Dir.** | **Last model** | **Coef.** | **SE** | **t value** | **Sign. <** | **Pa. R** | **$R^2$** |
|---|---|---|---|---|---|---|---|
| **$LP_4$-R** | Constant | 877.38 | 8.90 | 98.53 | 0.001 | - | - |
| | LL | -3.58 | 0.09 | -42.08 | 0.001 | -0.990 | 0.980 |
| | RL | -4.04 | 0.64 | -6.35 | 0.001 | -0.727 | 0.528 |
| | RA | 10.51 | 0.40 | 26.25 | 0.001 | 0.975 | 0.950 |
| | UTO | 17.64 | 1.06 | 16.66 | 0.001 | 0.941 | 0.885 |
| | LTO | -6.74 | 0.48 | -14.14 | 0.001 | -0.921 | 0.847 |

#### *5.1.8.3 Stepwise regression of BSKE and HHKE for thrower K6*

In general, the stepwise regression models of K6 were highly significant at $P < 0.001$, and the constant value was positive see table (17).

In Release phase $LP_4$-R of the trial K6, three body segments' kinetic energy were selected by the analysis, only LL correlated with the HHKE negatively, with $R^2$ values 99.9%, whereas the LA and LTO correlated positively with HHKE and the $R^2$ values were 98.6 and 98.7%%; respectively. $R^2$ values revealed that LL as the most effective value on the HHKE in this direction. The other values of RA, RL, UTO and Head were excluded by the stepwise regression analysis. Therefore, HHKE predictor equation

$$HHKE_{LP4\text{-}R} = 1084.6 + 6.1\ LA + 1.8\ LTO + (-14.7\ LL)$$

Table 17. Stepwise regression model of the body segments to the hammer head kinetic energy (HHKE) for the release phase for thrower K, trial 6

| Dir. | Last model | Coef. | SE | t value | Sign. < | Pa. R | R2 |
|---|---|---|---|---|---|---|---|
| $LP_4$-R | Constant | 1084.62 | 2.82 | 385.00 | 0.001 | - | - |
| | LL | -14.69 | 0.08 | -174.03 | 0.001 | -0.999 | 0.999 |
| | LA | 6.12 | 0.12 | 51.58 | 0.001 | 0.993 | 0.987 |
| | LTO | 1.80 | 0.04 | 49.85 | 0.001 | 0.993 | 0.986 |

### 5.1.9 The relationship between BKE and HHKE in Release phase of all trial of athlete H.

Here the focus would be on the simple regression between the BKE and HHKE during release phase.

In table (18) illustrated the analysis of variance of linear regression of BKE and HHKE of Thrower H trials. Generally, the models in each trials were significant at $p<0.001$. Accordingly, there is no output equation for the directions with non-significant coefficient for the independent variable.

Table 18. Analysis of variance of simple regression between BSKE and HHKE for thrower H trials

| Trials | Phases | | DF | MS | F | Sign. < |
|---|---|---|---|---|---|---|
| H1 | $LP_4$-R | Regression | 1 | 79384 | 168.9 | 0.001 |
| | | Residual | 34 | 470.06 | | |
| H3 | $LP_4$-R | Regression | 1 | 180259 | 144.3 | 0.001 |
| | | Residual | 43 | 1249.4 | | |
| H4 | $LP_4$-R | Regression | 1 | 84641 | 76.8 | 0.001 |
| | | Residual | 33 | 1102.72 | | |
| H5 | $LP_4$-R | Regression | 1 | 62663 | 96.7 | 0.001 |
| | | Residual | 43 | 648.10 | | |

#### *5.1.9.1 The relationship between BKE and HHKE during Release phase in H1*

The coefficients was significant at $p<0.001$ and positive (Table 19). BKE represented 83% of variance in Release phase LP4-R. The predictor equation of this trial was

$$HHKE_{LP4\text{-}R} = 1222.4 + (-1.3\ BKE)$$

Table 19. Simple regression model (Line) between BKE and HHKE, coefficient of determination ($R^2$) and standard error of estimate (SE) in release phase for thrower H, trial 1

| Dir. | Last model | Coef. | SE | t value | Sign. < | $R^2$ | SEe |
|---|---|---|---|---|---|---|---|
| $LP_4$-R | Constant | 1222.4 | 14.8 | 82.5 | 0.001 | | |
| | BKE | -1.3 | 0.1 | -13.0 | 0.001 | 0.83 | 21.68 |

#### *5.1.9.2 The relationship between BKE and HHKE in during Release phase in H3*

The coefficient was significant at $p< 0.001$ and positive. BKE represented 77% of variance during LP4-R phase see table (20). The predictor equation of this trial was:

$HHKE_{LP4\text{-}R}$ = 1412.7 + ( - 2 BKE )

Table 20. Simple regression model (Line) between BKE and HHKE, coefficient of determination ($R^2$) and standard error of estimate (SE) in the release phase for thrower H, trial 3

| Dir. | Last model | Coef. | SE | t value | Sign. < | $R^2$ | SE |
|---|---|---|---|---|---|---|---|
| $LP_4$-R | Constant | 1412.7 | 28.5 | 49.5 | 0.001 | | |
| | BKE | -2.0 | 0.2 | -12.0 | 0.001 | 0.77 | 35.3 |

##### *5.1.9.3 The relationship between BKE and HHKE in during Release phase in H4*

The coefficient was significant at p< 0.001 and positive. BKE represented a range between 70% of variance for all directions. The predictor equation of this trial was

$HHKE_{LP4\text{-}R}$= 1483.3 + ( - 1.3 BKE )

Table 21. Simple regression model (Line) between BKE and HHKE, coefficient of determination ($R^2$) and standard error of estimate (SE) in release phase for thrower H, trial 4

| Dir. | Last model | Coef. | SE | t value | Sign. < | $R^2$ | SE |
|---|---|---|---|---|---|---|---|
| $LP_4$-R | Constant | 1483.3 | 24.6 | 60.4 | 0.001 | | |
| | BKE | -1.3 | 0.1 | -8.8 | 0.001 | 0.70 | 33.2 |

##### *5.1.9.4 The relationship between BKE and HHKE in during Release phase in H5*

The coefficient was significant at p< 0.001 and positive (Table 22). In Release phase ($LP_4$-R), BKE represented 69% of variance. Therefore, the predictor equation of this trial was

$HHKE_{LP4\text{-}R}$= 1290 + ( - BKE )

Table 22. Simple regression model (Line) between BKE and HHKE, coefficient of determination ($R^2$) and standard error of estimate (SE) in release phase for thrower H, trial 5

| Dir. | Last model | Coef. | SE | t value | Sign. < | $R^2$ | SE |
|---|---|---|---|---|---|---|---|
| $LP_4$-R | Constant | 1290.0 | 15.8 | 81.9 | 0.001 | | |
| | BKE | -1.0 | 0.1 | -9.8 | 0.001 | 0.69 | 25.5 |

#### 5.1.10 The relationship between BKE and HHKE in during Release phase for Thrower K

In table (23) illustrated the analysis of variance of linear regression of BKE and HHKE of Thrower K trials. Generally, the models of all phases for all trials were significant at p<0.001.

Table 23. Analysis of variance of simple regression between BSKE and HHKE for thrower K trial

| Trials | phases | | DF | MS | F | Sign. < |
|---|---|---|---|---|---|---|
| **K2** | $LP_4$-R | Regression | 1 | 402895 | 761.9 | 0.001 |
| | | Residual | 41 | 528.8 | | |
| **K3** | $LP_4$-R | Regression | 1 | 34682 | 451.3 | 0.001 |
| | | Residual | 40 | 76.9 | | |
| **K6** | $LP_4$-R | Regression | 1 | 77396 | 486.7 | 0.001 |
| | | Residual | 38 | 159.0 | | |

### *5.1.10.1 The relationship between BKE and HHKE in during Release phase in K2*

The coefficient of X and Y were significant at p< 0.001 and positive (Table 24). In Release phase ($LP_4$-R), BKE represented 95% of variance. The predictor equation of this trial was

$$HHKE_{LP4\text{-}R} = 1536.4 + ( - 1.9\ BKE )$$

Table 24. Simple regression model (Line) between BKE and HHKE, coefficient of determination ($R^2$) and standard error of estimate (SE) ) in release phase for thrower K, trial 2

| Dir. | Last model | Coef. | SE | t value | Sign. < | $R^2$ | SE |
|---|---|---|---|---|---|---|---|
| **$LP_4$-R** | Constant | 1536.4 | 10.1 | 152.3 | 0.001 | | |
| | LL | -1.9 | 0.1 | -27.6 | 0.001 | 0.95 | 23.0 |

### *5.1.10.2 The relationship between BKE and HHKE in during Release phase in K3*

The coefficient was significant at p<0.001 and positive. In Release phase ($LP_4$-R), BKE represented 92% of variance (Table 25). The predictor equation of this trial was

$$HHKE_{LP4\text{-}R} = 1173.5 + ( - 0.8\ BKE )$$

Table 25. Simple regression model (Line) between BKE and HHKE, coefficient of determination ($R^2$) and standard error of estimate (SE) in release phase for thrower K, trial 3

| Dir. | Last model | Coef. | SE | t value | Sign. < | $R^2$ | SE |
|---|---|---|---|---|---|---|---|
| **$LP_4$-R** | Constant | 1173.5 | 4.7 | 247.6 | 0.001 | | |
| | BKE | -0.8 | 0.0 | -21.2 | 0.001 | 0.92 | 8.8 |

### *5.1.10.3 The relationship between BKE and HHKE in during Release phase in K6*

The coefficient was significant at p< 0.001 and positive. In Release phase ($LP_4$-R), BKE represented 93% of variance (Table 26). The predictor equation of this trial was

$$HHKE_{LP4\text{-}R} = 1276.7 + ( - 1.1\ BKE )$$

Table 26. Simple regression model (Line) between BKE and HHKE, coefficient of determination ($R^2$) and standard error of estimate (SE) in release phase for thrower K, trial 6

| Dir. | Last model | Coef. | SE | t value | Sign. < | Pa. R | $R^2$ |
|---|---|---|---|---|---|---|---|
| **$LP_4$-R** | Constant | 1276.7 | 6.6 | 192.0 | 0.001 | | |
| | LL | -1.1 | 0.0 | -22.1 | 0.001 | 0.93 | 12.6 |

## 5.2 Results of Measurement Information System (MS)

Of the throws of the athletes, 3 trials were chosen based on the next criteria: The best estimated-distance trial (K2), see table (8), the first trial regardless the distance (H1) and the shortest estimated distance among the last trials in order (K3). The first trial was the first data was recorded by the measurement information system, the best trial supposes to present the highest values in acceleration, strain force and angular velocity, the last as same as the worst to verify the validity of the measurement after impacting the system to the special throwing-Curtains, as mentioned in the research method chapter. The air resistance was ignored because it was indoor throws.

This chapter addresses a comparison between the hammer head variables obtained from the motion analysis (MA) and those which were obtained from the measurement system (MS), in order to judge the validity of the system to be used as hammer throw measurement unit. To normalize the output data frequency of the system with those from MA, means were calculated to be 300 data/second instead of 1952 data/second. It is noteworthy that the output data obtained from MS is unsmoothed, unlike the output data of MA which is smoothed with Butterworth technique. Furthermore, the variables are based on each other because they are all driven from the coordinates that resulted from tracking the motion, but the signals from sensor were independent from each other, each of them reacts individually according to its sensitivity to the change in motion.

White-gray bar above each curve represents the support phases and the red vertical lines refer to the high (H) and low (L) point positions. Acceleration and angular velocity in the horizontal plan, vertical acceleration, and the tension force.

### 5.2.1 Strain force

Strain Force is the force that resulted from the tension in the wire or the deformation of the wire diameter according to the force applied on it, while force from Simi was calculated as the centrifugal force (angular velocity and radius). Figure (51) shows the curves of the two measured forces for the chosen trials. It illustrated generally the same tendency of the curve values over the turns increasingly and decreasingly. The force increased gradually in coincidence with the begin of the DS phase to reach the high peak at the LP, then it decreased to reach to lower peak in the turn at the HP. The fluctuations look more in the simi curves than the curves from the SFS. In other words, the SFS curve was smoother than the other. The best throw (Figure 51b) had the higher forces values that presented by the two measurement's methods. Figure (51d) shows the validity of the MS to sense the differences in force of different performance levels.

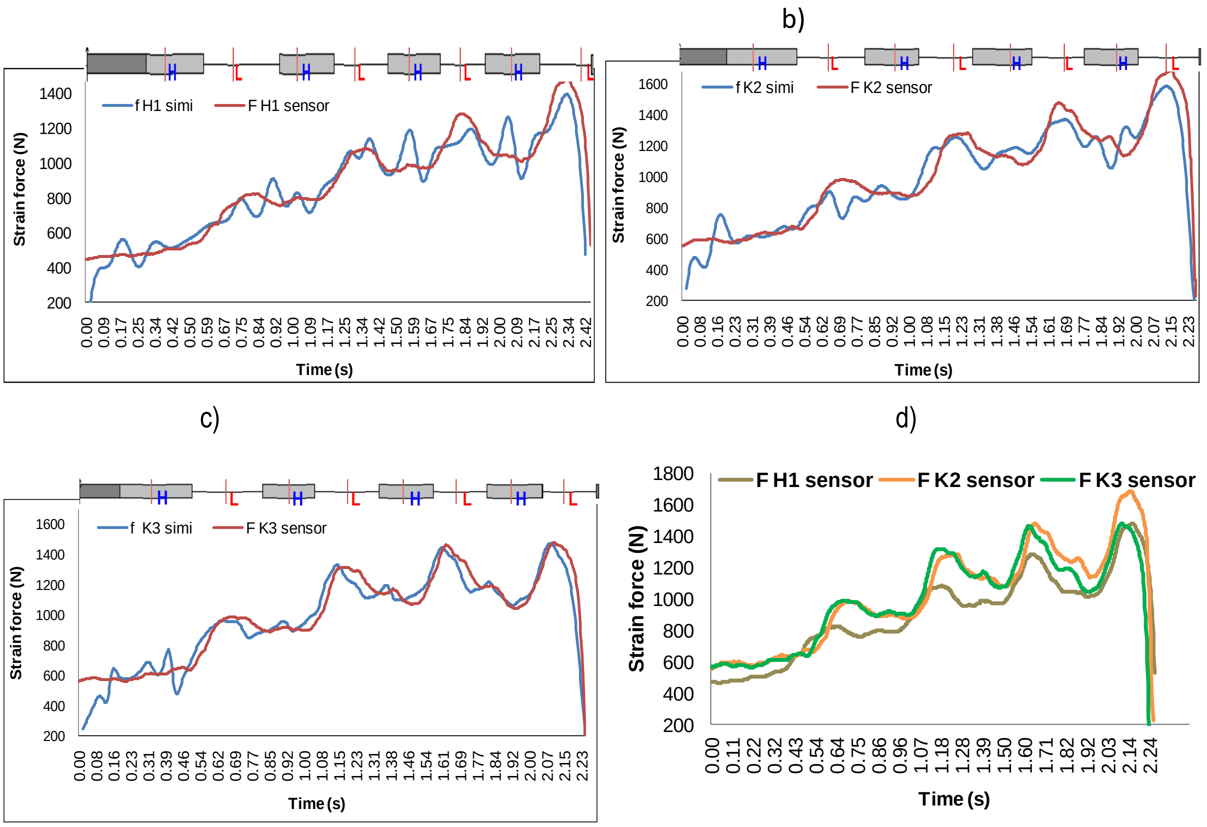



Figure 51. Graphs of strain force from MS (red line) and MA (blue line) of the three chosen throws a) H1, b) K2 , c) K3 and d)all trials from MS

## 5.2.2 Accelerations

Figure (52) shows the absolute value of acceleration of X and Y in purpose to obtain the acceleration in the horizontal plane. The curve illustrated the general compliance tendency during the performance between the calculated acceleration from MA and those from MS. In figure (52a), the sensor curve was smoother than the simi curve comparing to the other figures (52.b and c).

Generally the acceleration was increasing coinciding with reaching HP to reach the highest peak at the LP or after. The best throw (Figure 52b) had the higher acceleration values that presented by the two measurement's methods.

On the other hand, despite similarity or symmetry in shape, there was a difference between the values, the result obtained from the sensors in range between 100 and 200 m/s², while the acceleration obtained from MA in range between 10 and 330 m/s².

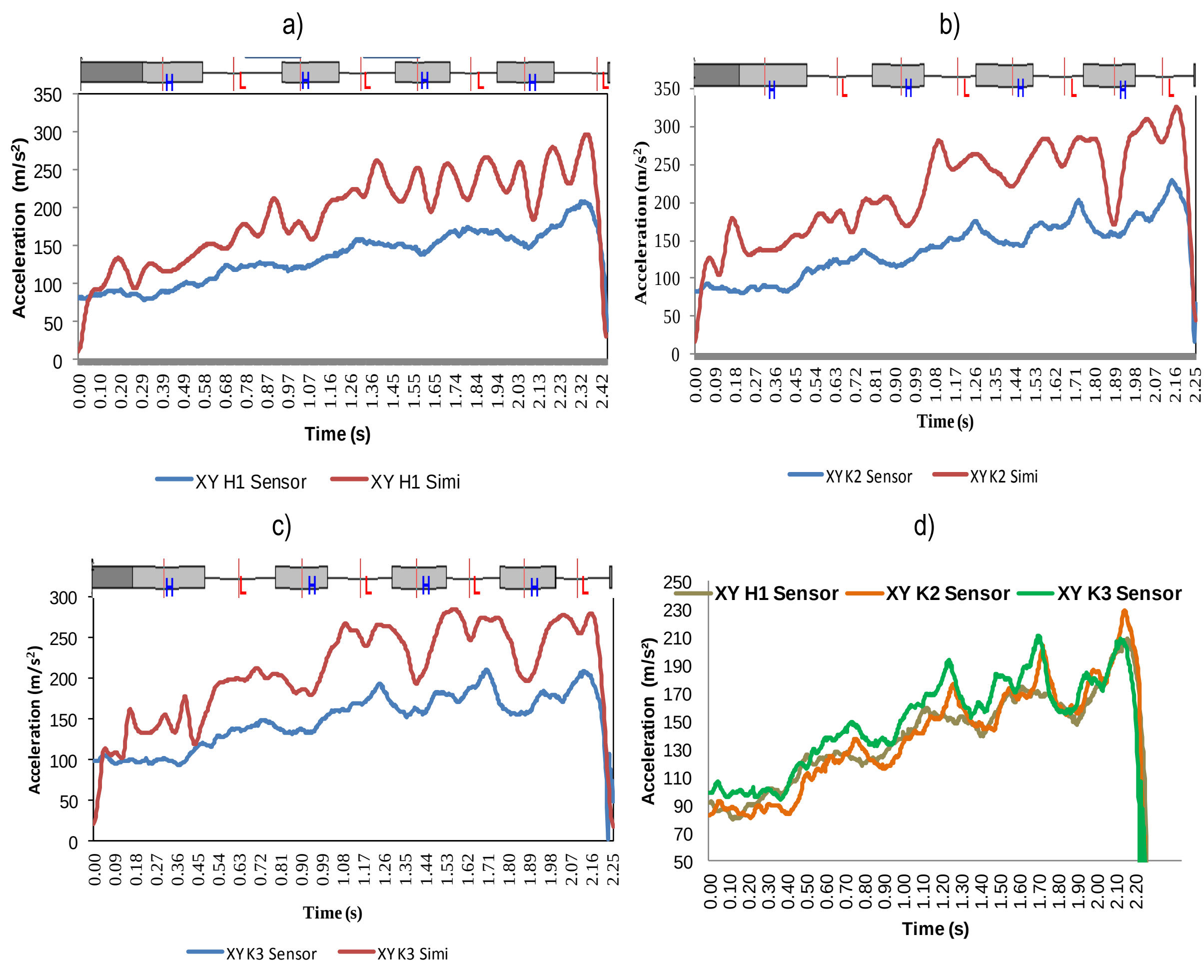



Figure 52. Graphs of the acceleration in the  horizontal plan (XY) resulted from MA (red line) and MS (blue line) of the three chosen throws a) H1, b) K2, c) K3, and d) all trials from MS

### 5.2.3 Angular velocity

Figure (53) shows the angular velocities values on the horizontal and the vertical plan, which were obtained from the MA and the MS for the chosen throws. The figures illustrate the similarity in the tendency generally for the increment and decrement phases in the turns and gradually increased from turn to turn and the amplitudes get wider towards the end.

For the angular velocity XY, each turn had two peaks mostly one at the HP the other at the LP. The peak amplitude at the HP from MA was higher than that at LP, which was contrary to gyro signals. The values of the angular velocity that obtained by gyros were higher than which obtained from MA, but the amplitudes distance values were close.

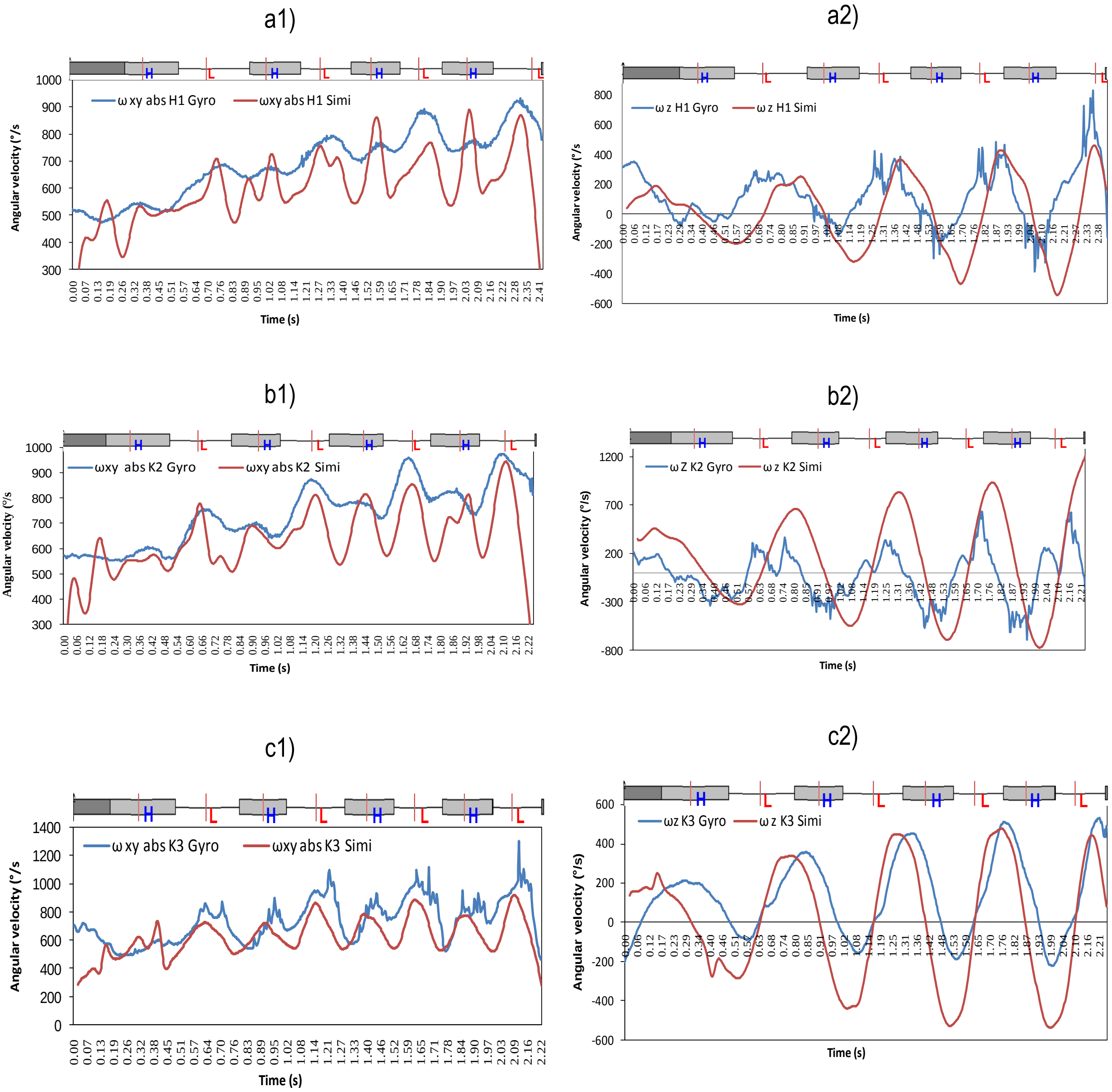



Figure 53. Graph of angular velocity from MA (red line) and MS (blue line) of the three chosen throws, since a1) H1 angular velocity XY, a2) H1 angular velocity Z, b1) K2 angular velocity XY, b2) K2 angular velocity Z, c1) K3 angular velocity XY and c2) K3 angular velocity Z

For the angular velocity z (figures 53.a2, b2, and c2), It was noticed that the MS senses two peaks per turn unlike those which resulted from MA. Furthermore, there was like a shift in peaks position, in other words, the curves obtained from MA occurred before those that were obtained from MS. The angular velocity increment phase regarding to the gyros curve coincides with HP and reached the main peak at the end of the DS. but for MA, the increase phase began synchronizing with the end of DS phases and the peak at the end of the SS, which referred to the shift that mentioned before.

Figure (54) shows the absolute angular velocity of the 3D of the chosen throws. They also illustrate the big similarity between the two curves in each figure also at the range value of the angular velocity. For each turn there were two fluctuations in MS curve against three per turn in the MA curve. The main or highest peak value coincides with LP while the other with HP. Generally, the increase phase of angular velocity was longer than the decrease phase.

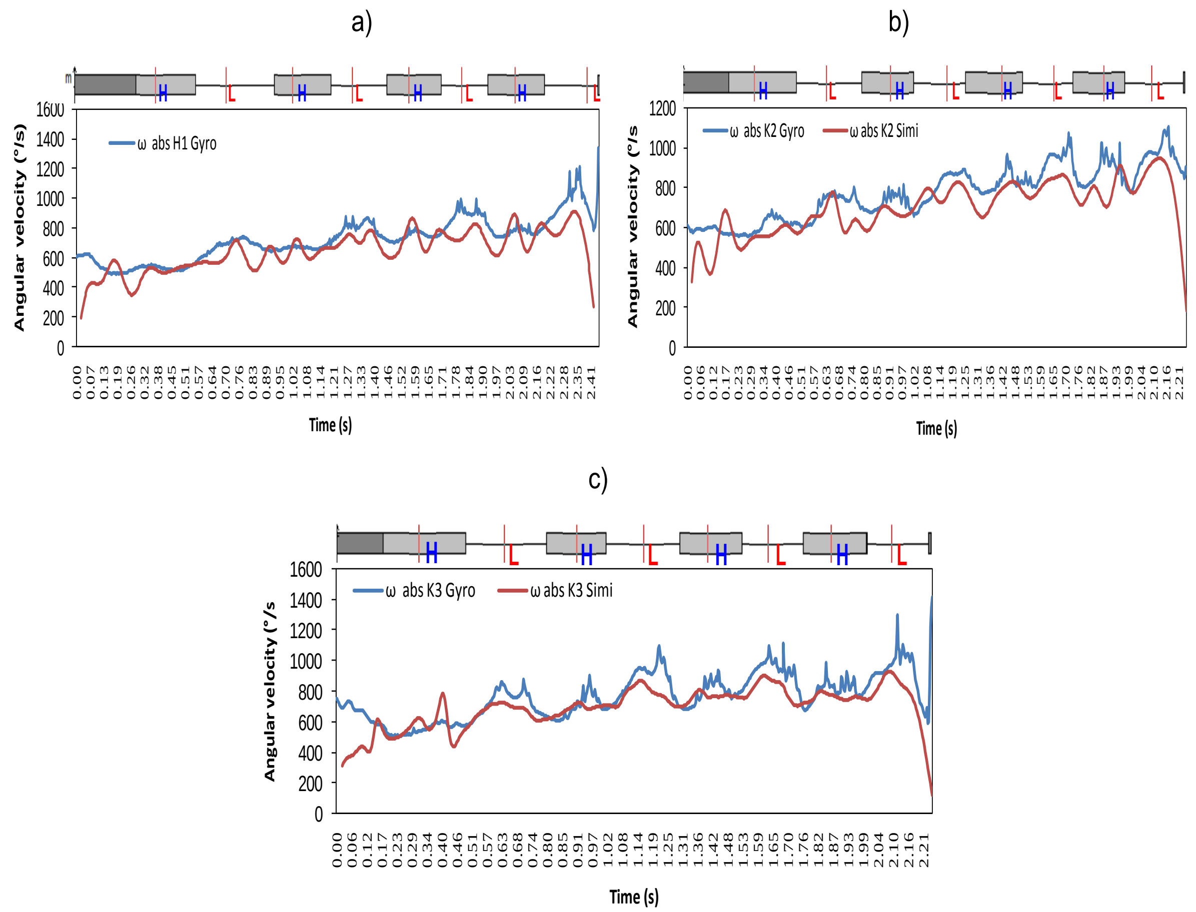



Figure 54. Graphs of the absolute angular velocity 3D from MA (red line on) and MS (blue line) of the three chosen throws, since a) H1, b) K2 and c) K3

# 6 Discussion and Conclusion

## 6.1 Discussion of Kinetic Energy Results

Every elite athlete builds through years of hard training their own techniques and elevates his/her performances. Biomechanics is an effective and essential way in diagnosing and improving individual performance, moreover it's a unique method in predicting and creating new techniques (e.g. fospry high jump). Motion analyses with different methods and techniques have been used as a parameter to collect the top performances techniques from elite athletes, in order to use it as a hand book for beginner and intermediate athletes.

Accelerating the hammer is the main goal of throwers. They should try to establish an optimal path of the hammer head from turn to turn, as well as to make the targeted speed of the hammer head with a series of repeated SS and DS phases each turn, in order to achieve the best height, velocity and angle of release. Researches state that the velocity of release is the most effective factor plus the other two indicators mentioned above.

Modeling and simulating the performance is the way to test the hypotheses of the new theories from other fields of science and its effect on the output. Like the prediction of the vacuum and wind on the hammer throw distance, which couldn't be tested normally by throw under controlled experiment, or to re-examine the mechanism to accelerate a hammerhead in hammer throw by comparing the motions of the hammer. The base to simulate the movement must be based on enough and accurate details about the movement to be able to change the conditions and examine the new effect.

The new in this study is quantifying the kinetic energy of hammer head, the thrower body and the body segments, in addition to testing the relationship among those parameters. As well as, it was a try to predict the final hammer kinetic by the body segments and the total body kinetic energy.

An inch in throw events can mean victory or defeat. Athletes and coaches alike leave no stone unturned in the ceaseless search for knowledge to improve performance. Track and field and specially hammer throw event, wherein technical skills are combined with aspects of strength and conditioning to enhance the performance. When athlete learns the pattern of movement well, he is able to describe the wrong with his movement (Judge and McAtee 1999).

The understood conclusion of biomechanical diagnose of a hammer thrower by the coach can make a significant difference in the performance, by attempted to bridge the gap between the researcher and the coach (Judge et al., 2008).

There is a difference between proper biomechanical technique and the style; the first is which every thrower has to apply, and the style is determined by each athlete's unique characteristics that based on the biomechanics (Bingisser and Jensen, 2011). An unusual technique for an athlete may be necessary compensation, which in the case of another individual would be determinable to the efficiency. The coach needs to recognize that many somewhat different movements may be efficient and correct for a given purpose, depending upon the individual performing (Liset, 2004). That what is found by observing the differences between both of throwers (H and K) especially in the HKE.

Since the human body consists of weights (masses of body segments), levers (bones), and devices for producing force (muscles and nerves), it responds to the laws of mechanics just as many other system of weights and levers. The problem is to determine how the body weights can be handled, so as to maintain stability at rest or in motion and to produce and control dynamic force in the performance of various types of technique, so that the desired result can be obtained (Liset 2004)

### 6.1.1 Characterization of BKE, HHKE and BSKE

Murofushi et al. (2007) reported that the increments of the hammer head's speed near LPs of the hammer head. In the current study, the change in the energy cycle is associated with changing from/to HP and LP. There were two high peaks of the HHKE in each turn, the first was located near the LP, the second was at the end of the DS phase. This result is partially agree with the result of Murofushi et al. (2007) . But it has to be mentioned that for thrower H, the characteristic of the first group trials' curve (H4 and H5) differed from the second group trials (see the groups in Table 8), since they were more smooth and had a specific attitude of increment and decrement (Figure 55 and 56).

On the other hand, all the HHKE curves of the thrower K had the same characteristics with little bit difference in the values of the Kinetic energy. The higher peak of the HHKE located at the end of DS phase in each turn.

The general tendency reflected no differences among the values of HHKE during the turns but in the last phase before throw which begin at LP4, especially in the first group-distance trials (H4, H5, and K2). That indicted the importance of this phase for transferring high kinetic energy by increasing the hammer head speed which due to a better distance. It is worth noting, that BKE values had the same attitude, when we compare between the first and the second group trials, but the body has achieved the highest values before the $LP_4$ is followed by a sharp decrease afterwards, which resulted from braking the body by the legs after $DS_4$ attempting to deliver the HH with arms and upper limp to the release point. This sequence may refer to the transfer of the energy from the body to the hammer during the last phase.

HHKE cycle was from the beginning of the SS to the next (ended by the end of the DS). On the other hand, BKE cycle began with reaching the HP and ended by reaching the next before-HP. Each cycle divides into stages the increment and decrement.

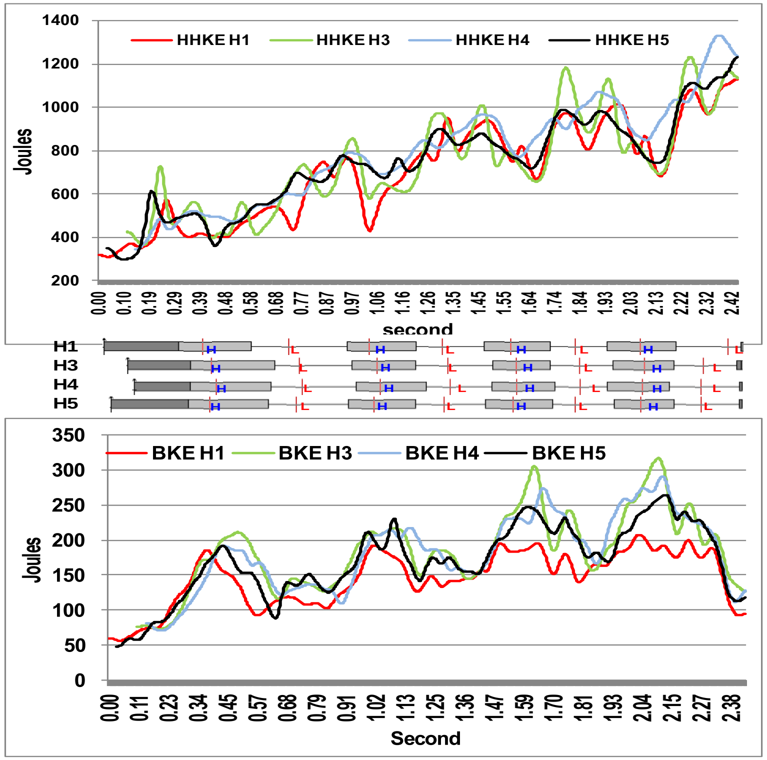



Figure 55. a) HHKE and BKE of thrower H trials (H1,H3,H4,and H5)

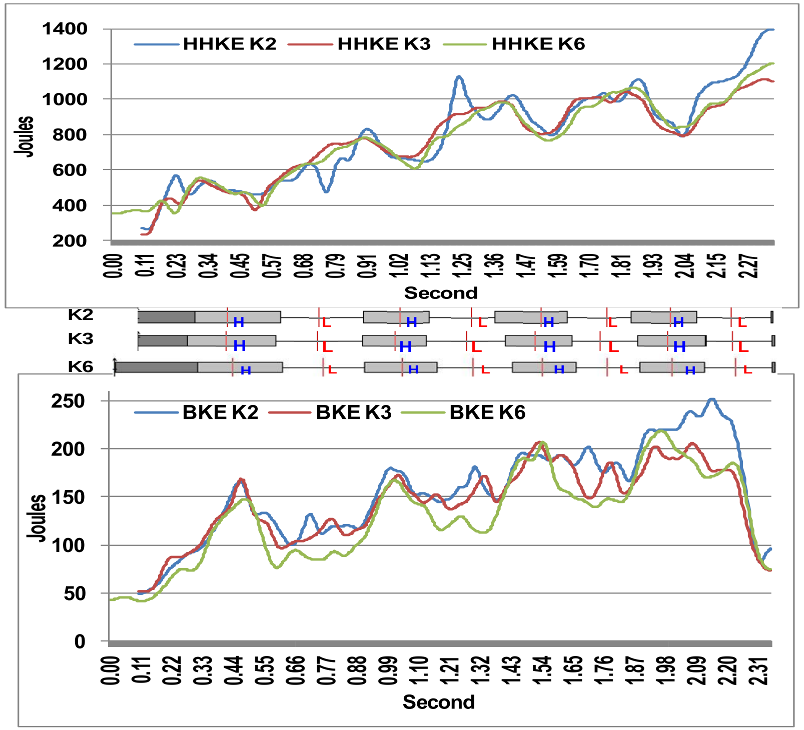



Figure 55. b) HHKE and BKE of thrower K trials (K2, K3, K6)

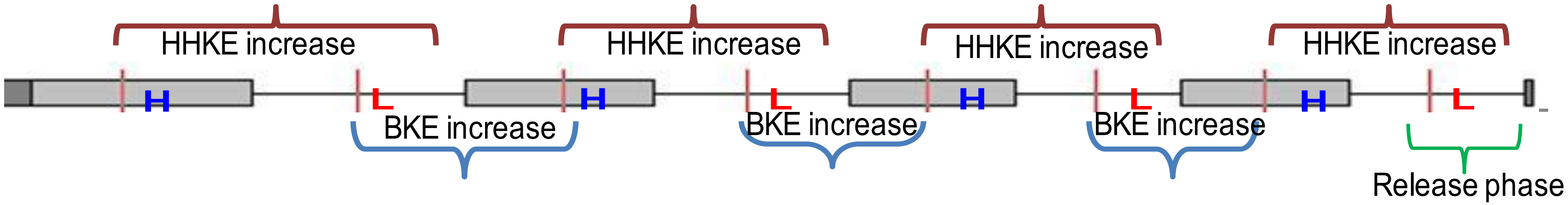



Figure 56.Sumerization of the incremant satges of BKE and HHKE according to the location in performance phases, where the white bar is the DS , the gray bar is the SS, (L) is Low point, and (H) is high point

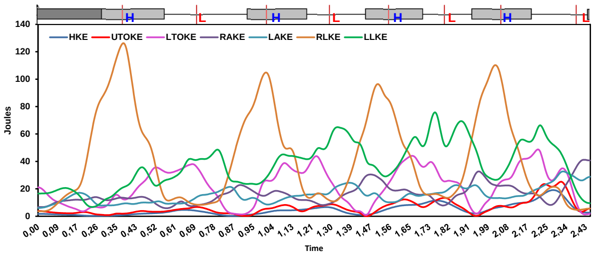
The HHKE decrement stage was from the beginning of SS to HP. The increment stage was from HP to near DS end, which agrees with Akira (2005) and Okamoto et al. (2008) that the velocity of hammer head was highest when passing around the LPs and lowest when passing the HP from the ground. The decrement of BKE was from after-HP to LP, and the increment was from LP and HP. This classification indicated that the stage of HHKE decrement duration was shorter than increment. The two stages of the BKE were relatively similar. Henceforward, there was a duration (from LP and the end of DS) where both of BKE and HHKE increased together. Ohta et al. (2010) refered to this duration of time when the athlete try to lower his center of mass and prepare to rise his right foot to begin the SS phase. The condition that makes the time derivative of the energy positive is derived as energy pumping for the hammer and the condition is expressed in terms of the tugging force times velocity to pump hammer energy. Tugging near the low point gives the optimal way to yield maximized restored energy in each turn, because the tensile force reaches a local maximum near the low point. This is an approach for restoring kinetic energy using parametric excitation which is a principle to increase energy.

### 6.1.2 Segmental Sequence of KE of body segments during turns

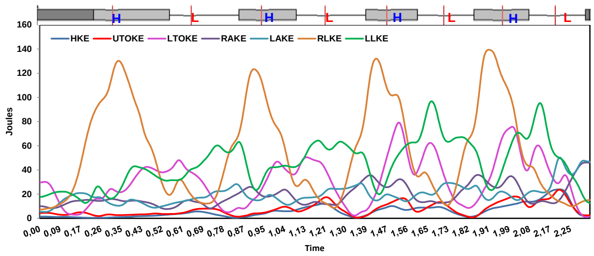
In Regard to the segment's kinetic energies curves (Figure 57), the order of the peaks (maximum values) from the greater to the lower for athletes H begins with RLKE, LLKE, LTOKE, RAKE and LAKE, UTOKE finally Head. The same order was found for the trails for athlete K, except in k6 where the LTOKE exceeded the LLKE. Another notice of athlete K conserning the HKE, that was the Head started from the third turn to be in the third place and at the last DS was greater than LLKE inspite of having the smaller mass . That indicated to the role of the head in athlete K's style for increasing the total body KE.

Judge and McAtee (1999) and Judge (1999) consideres that controlling torso is crucial for a good position, which means the more solid the torso is, the more solid the throw is. The current result above found that the LTOKE and the UTOKE peaks was happening parallel, regardless of the value itself, except of a slight twist, which means that the athletes used the torso as solid lever to transfer energy from point to point.

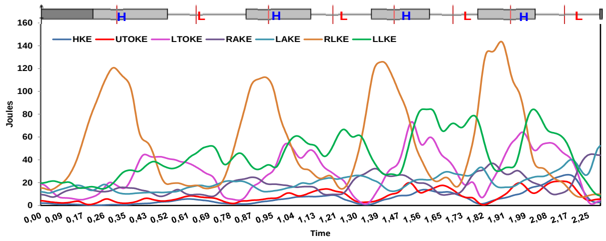
Murfushi et al. (2007) discussed the theory about the balance, if the hammer head speed is increased sufficiently near the low point, then the body rises with the hammer during the transition to the SS. Therefore, it is important to rotate the hammer about the rotational axis by lowering the body by utilizing gravity while avoiding raising the centre of mass. In the current study, the HH is accelerated around the rotational axis in the duration from LP to the end of DS then there was a combination of acceleration mainly around the rotational in addition the throw direction. If the centre of mass rises, the hammer can not rotate about the rotational axis and the hammer is subjected to body



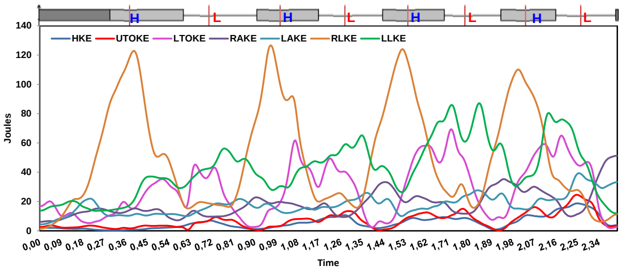

**a)** Body segments curves of athlete H1



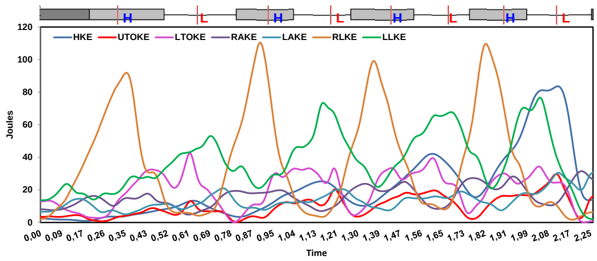

**b)** Body segments curves of athlete H3



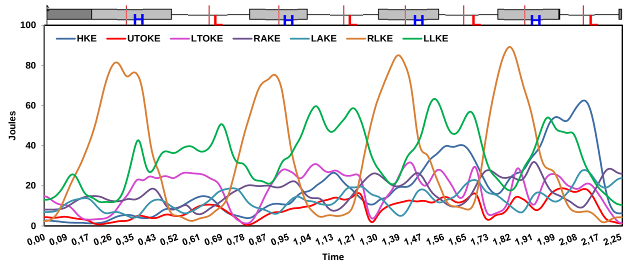

**c)** Body segments curves of athlete H4



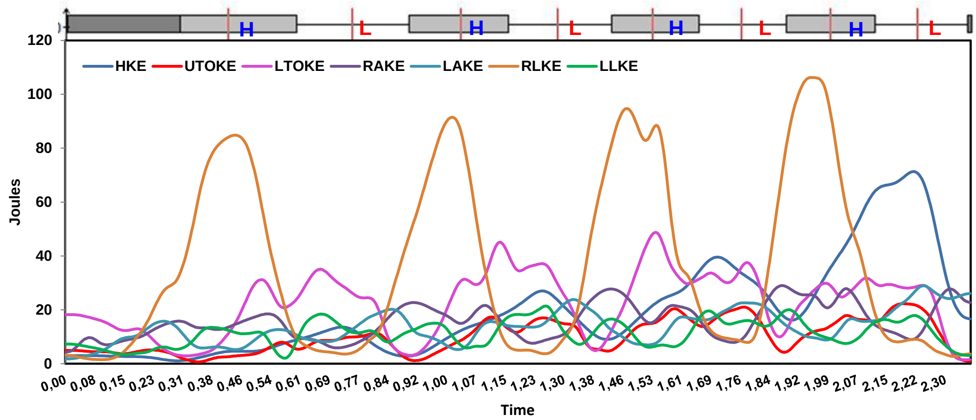

**d)** Body segments curves of athlete H5




**e)** Body segments curves of athlete K2




**f)** Body segments curves of athlete K3




**g)** Body segments curves of athlete K6

Figure 57. BSKE curves of all trials for both throweres H and K

weight, thus reducing the hammer head speed. In addition, this makes it difficult to make a smooth transition to the double support phase. In the current study, about the LP the HHKE continue increasing and the BKE is still low. Figure (58) show a simple summary of the BSKE peaks position during turns. It's worth to mention that each of UTO, LTO, And LL kinetic energies curves had a wide peak that refered to being in their high values for a while and not a sharp peake like RLKE curve. During the DS, when we compared the work of the two legs we found that the LLKE has reached the peak by the LP while the RLKE values still the lowest then reaches the peak after a while. This result is in harmony with the opinion of Morufushi et al. (2007) that the vertical load is switched from the right foot to the left foot and the right foot mainly contributed to the horizontal direction component. Therefore, The left foot should react to the initial, rotating action of the right foot, and should not attempt to initiate this horizontal force into the movement of the hammer. In other words, the ground reaction force exhibited repeated patterns in which the left and right feet were used differently.

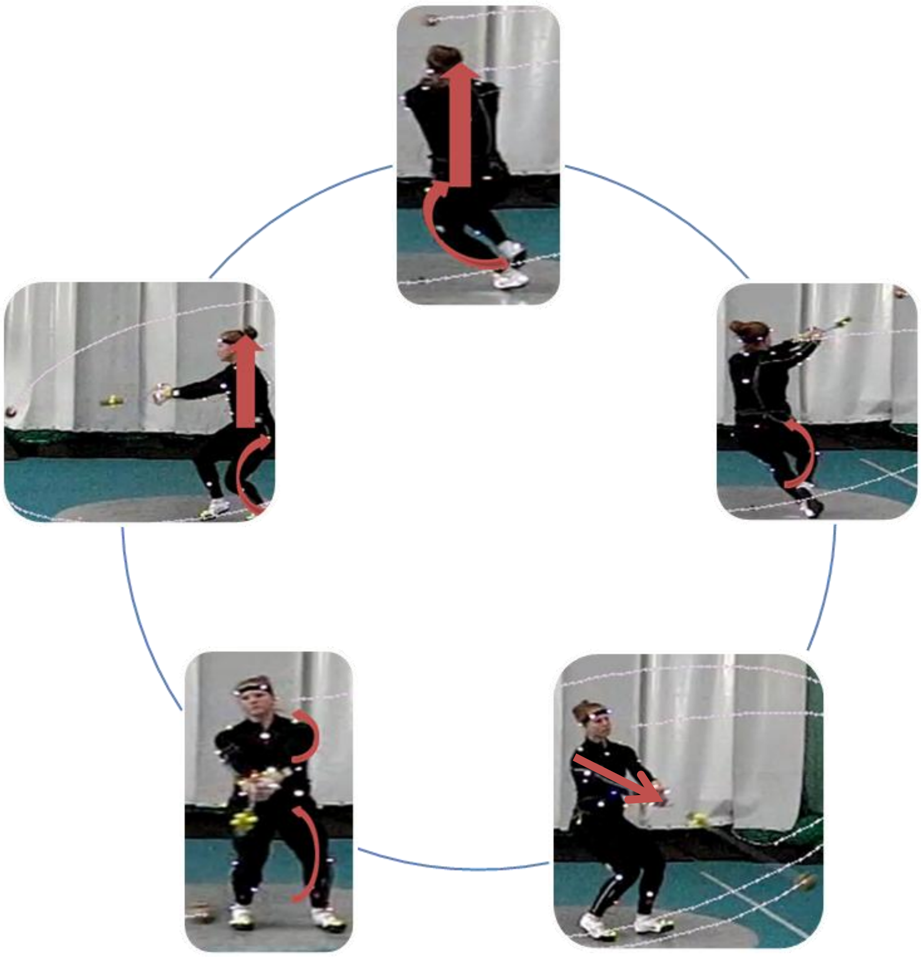


Figure 58. BSKE peakes, as exymple, in one turn. where the red arrow referes to the segment which has the peak energy in this pahse of performance

Also the minimum and maximum values of BKE and HHKE increase from turn to the next, and we notice very slight change in the minimum values for each segment, but the maximum value increased highly except LAKE and LTOKE (only in the last 2 turns) and it seems the opposite in the case of RL (reaches the peak during the SS near HP), in its un-comparable contribution to the HHKE during SS. That means leading of the hammer during the single support phase is made only by the right leg. Bingisser and Jensen (2011), Bunderchuk (2010) and Judge and McAtee (1999) reported that the effective leading of the hammer by the lower limbs only with the help of an actively rotating right leg, because the role of the right leg / left leg and pelvis involves an extremely high degree of isometric work. On the other hand, the small quickening at the HP is attributed to the tendency to bend the left leg before landing on the right leg, thus at this moment, when the whole system of the appliance lowers.

### 6.1.3 The relationship between the BSKE and both of BKE and HHKE during turns and release

Here the contribution and correlation between each of the BKE and BSKE from one hand, and the HHKE on the other hand, is to clarify the effect of the BSKE on the body and the hammer, and also to show the direct and indirect effect and interaction among them. The next discussion will be around 3 main points BKE increment phase, BKE decrement phase, at Release.

#### *6.1.3.1 BKE increment stage from LP to HP during turns*

Cook 2006 reported that if the body is the conduit through which force is conducted at the point of impact, then the more efficient the body is at conducting that force (minimizing absorption), the faster an object will be propelled through space and time, and the desired power for throwing the hammer relates strongly to the lower body power. This tends to suggest that the lower body power would be a better predictor of current performance, and that the future performance would be greatly influenced by training the lower body for higher power outputs.

*Contribution BKE & HHKE* showed that the total body kinetic energy percentage in this stage decreased gradually from turn to turn, and the highest value was in entry phase. Entry values in athlete H trials were higher than those of athlete K. and the difference between the entry and the next turn between 7% and 10% for H and between 1 and 8 % for K.

*Contribution BSKE & HHKE f*or both athletes throughout turns, showed that RLKE (4.8 - 19%) took the first place as a biggest contribution percentage among the rest kinetic energies of segments to the HHKE. The maximum percentage was observed in the first turn.

LLKE ( 3.5 and 7.4 %) took the second contribution place. It was observed the relative deference between RLKE and LLKE. In the third and fourth places came the RAKE (2 – 3%) and LAKE (1.5 – 3.2%). This indicated that the work in this stage depended on the limbs (Legs and Arms) while the H, LTO , and UTO had the last orders.

Except K6, wherein RAKE and LTOKE came over the LLKE in the order. As a technique style of athlete K, the HKE was in progress in the order from turn to turn coming over the rest of the segments kinetic energies to be the first in the release phase, where its contribution ranged between 0.4 and 2.6%. By observing the throwing movement of K, the head appeared to be used to increase the radius of curvature as a way to increase the inertia without creating a special rotation with head and to overcome her small weight comparing to then other athlete's weight

*Correlation BKE and HHKE:* For athlete K, in the second group-distance trials the relation was negative highly significant stronger in K3 than K6. And the best trial K2 reflected no specific attitude. For athlete H, it was not a clear or a defined relation and almost non-significant except in H5. So we can conclude that for better distance the BKE had either weak or no relation with HHKE, and it depends partially on the individual technique.

*Correlation BKE and the most contributed segments:* for both athletes there were no differences among the first and the second group of trials except K6, the correlation between the BKE and RLKE was positive and highly significant and it became gradually stronger from turn to turn. This result showed that increasing the kinetic energy or the velocity of the right leg had a significant effect on increasing the BKE specially in the first and the second turn until the body gain the needed inertia to keep moving. The increment of RLKE matched the increment of BKE.

For athlete H, The correlation between BKE and LLKE showed a highly significant negative correlation except in the first turn. For athlete K, there was a difference between the first and second group trials, where the relation in K2 was highly significant negative, but in K3 had no specific attitude. This result in addition to the LLKE curve showed that decreasing the LLKE or LL velocity during this phase affected increasing the BKE and helped to achieve a good distance during turns.

*Correlation HHKE and the most contributed segments:* The correlation between HHKE and RLKE was either highly significant and weak or non-significant, the same for the relation between the LLKE and the HHKE, there was no specific attitude and in most phases was non-significant.

As a conclusion, the RL was the most effective segment that increased the BKE in this stage and this may be because of its direct positive relationship with the BKE. However, each of RLKE and BKE had no specific relationship with HHKE. Interestingly, the kinetic energy that produced by the RL instead of being added to the other energies by the other segments in its way to the hammer, is distributed or restored somehow to be pumped to the hammer at the beginning of the next increment HHKE phase.

#### *6.1.3.2 BKE decrement stage from HP to LP in turns*

While the hammer comes around, the leg should not be too active. The left side of the body is equally important during acceleration phase, but the left shoulder should not be pulled back, thus the radius will be reduced. the thrower and the hammer head should be accelerated together as a single unit (Bingisse and Jensen 2011).

The leading distance of the Handel (the displacement from the handle to the connecting line between the hammer head and instantaneous center of rotation and hammer head) has a positive effect on hammer head velocity when it is positive, it happened in the duration between short before the high points (HPs) to the low points (LPs) (Fujii et al. 2007). Susanka et al. 1986 recommended some technical points in order to achieve an increase in the velocity of the hammer head, included 1) Active and continuous leg action and never held in a static double-support position. 2) The rotating of the trunk ahead of the pelvis, with a shift of the center of the shoulder connecting line toward the right hip-joint. 3)The turning of the shoulder axis ahead of the hammer-wire axis. 4) The vertical lifting of the hip-joints against the direction of the vertical motion of the grip and hammer head. (Susanka et al. (1986).

*Contribution BKE and HHKE:* In the case of athlete H, the contribution of BKE to the HHKE was greater at the first turn in all trials except H5. For athlete K, only the K2 the first turn had the greatest contribution value of BKE. In general, the contribution values of the second turn were the inflection points, and after it the contribution values increase gradually.

*Contribution of BSKE to the HHKE :* LLKE came at the top of the contribution list, since it ranged from 4.9 to 8.1% in all phases. Afterwards, the RLKE and LTOKE were in the second and the third places alternately. Unlike the previous phase, Arms kinetic energies dropped to the last orders in the list.

It was the same thing for athlete K, the previous phase the HKE (1.5 – 6.6%) was progressing gradually in the order from turn to turn and coming over the rest of the segments kinetic energies to be the first in the release phase. In case of K6, the matter was completely different, since the LLKE was dropped down to the last rank.

*Correlation BKE and HHKE,* In the case of athlete H, BKE and HHKE exhibited negative and highly significant relationship except in trial H3. This relationship is very clear in the first group trials of athlete H. for athlete K, the correlation also negative and highly significant except in trial K2, since the correlation was undefined . Generally, the correlation coefficients were stronger in case of athlete K than in case of athlete H.

*Correlation BKE and the effective segments:* The significance, strength, and attitude of the relationship between BKE and LLKE was unclearly defined, while the correlation between the LLKE and HHKE was highly significant, positive, and strong in most cases.

The correlation between RLKE and BKE was positively highly significant and strong except in the fourth turn in both of H3 and K2 trials, while it was negative and highly significant with HHKE and scaled between moderate and strong.

The correlation between LTOKE and BKE was highly significant particulary with the first group of trials in this phase, it was positive, but in the second group of trials was undefined relationship. On the other hand, the relationship between HHKE and LTOKE was non-significant in most phases of the best trials of athlete H, and it was positive but weak in athlete K trials.

According to the previous results, the BKE has been affected by number of segments, because the RLKE and LTO had a direct relationship with BKE. In order to increase the HHKE in this phase, first the athlete has to reduce the RLKE and LTOKE that will reduce subsequently the total BKE, which is associated negatively with the HHKE. Second, the athlete has to work effectively with LL. Interestingly, the RL and LL had a direct and contrast effect on HHKE.

#### *6.1.3.3 Release ($LP_4$- R)*

If the three or four turns have been executed correctly, the speed and the orbit of the implement has to be increased on a smooth path of acceleration from turn to turn. The final acceleration comes from the extension of the knees, hips, back, and shoulders. The release should be thought of as going around the body and the athlete should push with the right leg. Therefore, in the beginning of the last turn, the thrower must concentrate on this last effort (Judge 1999)

Figure (55) shows a comparison between BKE and HHKE for both athletes separately. The last increase of the HHKE before release began immediately after $HP_4$, shortly after that the BKE began to decrease. The sharp changes in the BKE curves appeared correspondently with the $LP_4$, while the hammer head was accelerated first to the left then to the release direction and avoid accelerating vertically. This values of curves showed difference between the first and the second group of throws for both throwers (H and K). This sequence may be an indication to the transfer of the energy from the body to the hammer during the last phase, where the body tries to brake up the rotation with the lower limb, and the upper limp deliver the hammer to the release point. Therefore, it was noticed that the best throw was that the HHKE had just one peak at the release instance and had the highest value at all.

A highly significant and negative relationship (r, -0.83 to -0.97) between the BKE and the HHKE was observed. This study illustrated that in order to increase the HHKE and to achieve a good distance, the body has to decrease the movement as much as possible and the direction of work has to be focused on (X) and to avoid the acceleration of the HH vertically.

### 6.1.4 Predict the HHKE by BKE in LP-R phase

Next table (28) shows the prediction equations of HHKE by BKE. Wher was observed that the throws exceeded 60m were with constant exceeded 1400 Joule, this constant was considered as the rest energy or restored energy from the previous stage before adding or abducting BKE multiplied by factor. Thus the lower the BKE is, the greater the HHKE. On the other hand, the throws less than 60m, except H3, had constant less than 1400 Joules. Therefore HHKE in this phase could be predicted by the equations in the third column table (27), but for generalysing the calculations have to be on a bigger sample of trials.

Table 27. The equations of predicting hammer head KE by body KE In release phase of both athletes in all throws

| throw | Lp4-R |
|---|---|
| **K2 (66.83m)** | $HHKE_{LP4-R} = 1536.4 + ( - 1.9\ BKE )$ |
| **H4 (60.4m)** | $HHKE_{LP4-R} = 1483.3 + ( - 1.3\ BKE )$ |
| **H5 (57.4m)** | $HHKE_{LP4-R} = 1290 + ( - BKE )$ |
| **K6 (51.36m)** | $HHKE_{LP4-R} = 1276.7 + ( - 1.1\ BKE )$ |
| **H3 (49.4m)** | $HHKE_{LP4-R} = 1412.7 + ( - 2\ BKE )$ |
| **H1 (49.33m)** | $HHKE_{LP4-R} = 1222.3 + ( - 1.3\ BKE )$ |
| **K3 (48.70m)** | $HHKE_{LP4-R} = 1173.5 + ( - 0.8\ BKE )$ |

**How did the segments work during this stage?**

For athlete H, the kinetic energies of LL, LA and RA took the first three places in the contributions to the HHKE. While for athlete K, the kinetic energies of H, LA and RA took the first three places in the contributions to the HHKE. In both cases, the contribution of RL ranked the last place.

Regarding the correlation of these segments and both of BKE and HHKE, the correlation between LLKE and BKE was positive and highly significant, while it was approximately absolute and the correlation between LLKE and HHKE was negative and highly significant. This relationship was stronger in K trials than in H trials.

LAKE was correlated positively and highly significant with BKE in all trials with exception of H3, which was not significant, and LAKE was correlated negatively and highly significantly with HHKE in all trials with the exception of H3 too. In the second group throws of both athletes the correlation degree was stronger than in the first group throws.

With regard to the correlation between RAKE and BKE was negative, strong and highly significant, while it was positive, strong and highly significant with HHKE.

HKE was correlated positively and highly significantly with BKE and was absolute in K trials, while it was correlated negatively and highly significantly with HHKE and was very strong too.

Finally, the RLKE was correlated positively and highly significantly with BKE in all trials except H3 and K2 that was non-significant. the relationship between RLKE and HHKE was negative except H3.

For both athletes, the LAKE and RAKE took the second and the third as a participant on the HHKE, but with different attitude as the correlation coefficient above showed. That may be logic (RA positive, LA negative with HHKE) if we consider that both of athlete are right-handed, and if they depended on RA to apply force on the hammer specially at the release phase (LP4- R). At the same time the right shoulder joint, which involved in the RA segment, continue rotating towards the throw direction , unlike the left shoulder joint, which moved backward to brake down the upper torso and the body which due to rotating the athlete about her left side after release. This result competent with the indication that the HKE is the first in athlete K technique and the LLKE was in athlete H technique, they are both correlated negatively with HHKE, which referred to athlete H who used the left side of body to break down the body, while athlete K used the head and the left arm to reduce the body movement at the delivery phase. Furthermore they continue accelerating the Hammer with the right arm.

### 6.1.5 Could we find out a specific group of body segments that interact to achieve a better distance?

Alternative variable selection methods have been developed to identify good (although not necessarily the best) subset models, with considerably less computing than is required for all possible regressions. These methods are referred to as stepwise regression methods. Stepwise selection of variables requires more computing than forward or backward selection but has an advantage in terms of the number of potential subset models checked before the model for each subset size is decided. It is reasonable to expect stepwise selection to have a greater chance of choosing the best subsets in the sample data, but selection of the best subset for each subset size is not guaranteed (Rawlings et al. 1998b).

The number of body segments , regarding to table (9, 14 and 28), that were involved in the regression analysis varied from trial to trial, the stepwise regression analysis has revealed differences between the second and first group trials and in the individual technique as well. For athlete H, in relaease phase ($LP_4$-R), (2-6) BSKE were involved in affecting on HHKE. The best trials had the following number of participants (H4, 2 segments) and (H5, 5 segments).

For athlete K, in relases phase ($LP_4$-R), (3-5) BSKE were involved in affecting on HHKE. The best trial K2 had four segments.

From the stepwise regression results, no specific difference has been observed in the constant of the regression model between the two trial groups in the duration started from $LP_4$. If we would like to predict the HHKE in the release phase, we have to use the regression models in table (28).

Table 28. The equation of predicting the HHKE by the most correlated BSKE with each other and the HHKE in the last phases

| Trials | Predicted equation (LP4-R) |
|---|---|
| **K2 (66.83m)** | HHKE= 1443.3 + 2.7 LTO + 0.7 UTO + ( -2.2 LL - 3.9 H) |
| **H4 (60.4m)** | HHKE= 1221+ (-14.9 RL – 2.6 LA) |
| **H5 (57.4m)** | HHKE=1232 + 7.5H + 9.4 RL+ 3.1 LTO + (-10.8 L L- 4.5 UTO) |
| **K6 (51.36m)** | HHKE= 1084.6 + 6.1 LA+ 1.8 LTO+ ( -14.7 LL) |
| **H3 (49.4m)** | HHKE= 1531.7+ 5.4 LL + 5.4 LA + 3.8 RL + ( -1.1 LTO - 36.2 UTO - 14.8 RA) |
| **H1 (49.33m)** | HHKE= 1336.1 + 9.5 LA + 3.3 RL+ ( -6-5 LTO - 10.5 RA - 12.3 H - 4.5 UTO) |
| **K3 (48.70m)** | HHKE=877.4+10.5 RA+17.6 UTO+(-3.6 LL-4 RL-6.7 LTO) |

However, the HKE, LLKE, LAKE, and RAKE were the most effective contribution to HHKE at this stage, but the stepwise regression analysis gave a different unexpected model. In the best trials of athlete k, the kinetic energies of head were included and the arms are excluded from the model for the whole phase and replaced with LLKE, LTOKE, and UTOKE. In the best trial of athlete H, the LAKE is included in the model, while the RAKE and LLKE were replaced with the RLKE in spite of being the RLKE in the last order of contribution. The conclusion of this apparently contrast between the linear correlation and contribution percentage on one side and the stepwise regression on the other side may be resulted from the nature of the analysis where the stepwise tests the internal-correlation among the inputs (independent variables) and the output (dependent variable). Judging for one side over the other require further studies with big sample.

### 6.1.6 Determine the transfered energy during release phase

Figure (59 and 60) presents the curves of the mathematical difference between the energy of BKE and HHKE in the last phase ($LP_4$-R) due to the sharp decrease in BKE and increase of HHKE values may reflect the amount of energy that has been transferred from the body to the hammer at the release phase. Both of the contribution's percentages of the BKE to HHKE in this phase and the calculated differences between this phase and the previous that ranged between 10.7 and 11.1% did not show a difference among the second group and first group-distance trials. However, the main difference was found in the kinetic energy values per second. For example, 10% out of 1400 Joules does not equal 10% out of 1500 Joules. is it right to assume that the lower the percentage contribution at the last stage is, the more the transferred energy is, and then the better distance is. Henceforward, the higher the value of the BKE before the 4th DS was, and the higher the value of HHKE was, and the higher the difference between the two values was, the bigger the amount kinetic energy transferred to the hammer. This also could be noticed from the pattern of athlete movment after releasing hammer and the balance.

b)

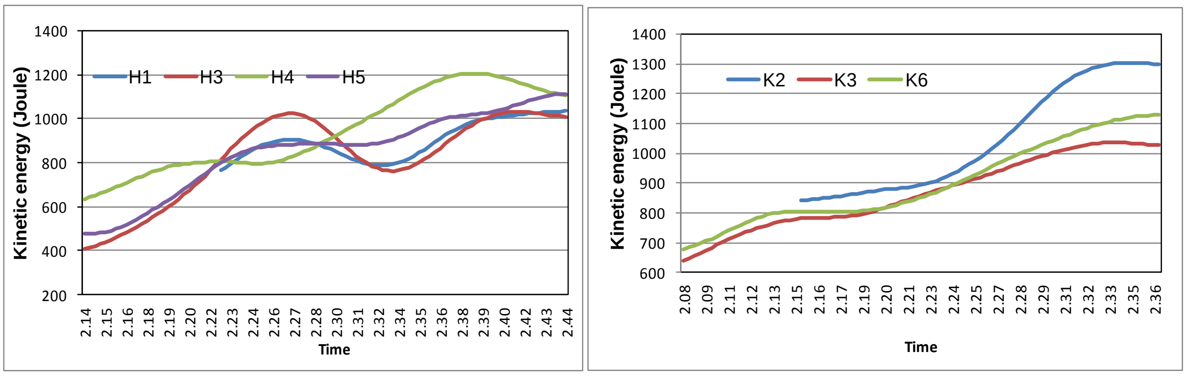



Figure 59. the mathenatical difference between the BKE and HHKE for the duration from the last high BKE peak to Release , where a) athlete H trials , b) athlete K trials

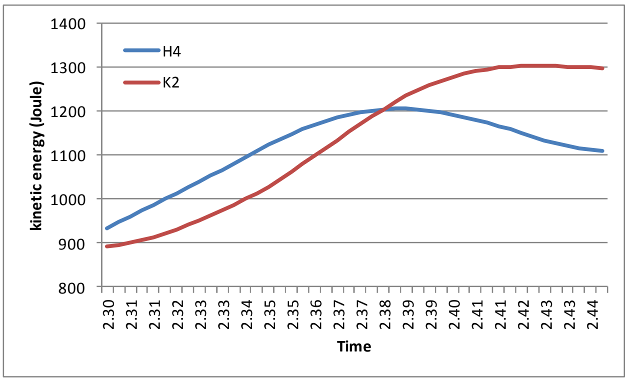



Figure 60. the mathenatical difference between the BKE and HHKE for the duration from the last high BKE peak to Release of the best trial of each athlete

## 6.2 The conclusion of Kinetic Energy results

The KE of both the BKE and HHKE was increasing from turn to turn, but not parallel to each other except duration from LP to the end of DS. The order of the peaks (maximum values) from the greater to the lower for athletes H begins with RLKE, LLKE, LTOKE, RAKE and LAKE , UTOKE finally Head. The same order was found for the trails for athlete K but it was found that the HKE started from the third turn to be in the third place and at the last DS was greater than LLKE in spite of having the smaller mass. That indicated to the role of the head in athlete K's style for increasing the total body KE.

It was found also that both the LTOKE and the UTOKE peaks was happening parallel, regardless of the KE value, except of a slight twist, which means that the athletes used the torso as solid lever to transfer energy from point to point. The result indicates that increasing HHKE was affected mainly by the RLKE.

**During BKE increment stage:** increasing the kinetic energy or the velocity of the right leg had a significant effect on increasing the BKE especially in the first and the second turn until the body gain the needed inertia to keep moving. The increment of RLKE matched the increment of BKE. Decreasing the LLKE or LL velocity during this phase affected increasing the BKE and helped to achieve a good distance. the RL was the most effective segment that increased the BKE in this stage and this may be because of its direct positive relationship with the BKE. However, each of RLKE and BKE had no specific relationship with HHKE. Interestingly, the kinetic energy that produced by the RL instead of being added to the other energies by the other segments in its way to the hammer, is distributed or restored somehow to be pumped to the hammer at the beginning of the next increment HHKE phase.

**During BKE decrement stage** LLKE came at the top of the contribution list. Afterwards, the RLKE and LTOKE were in the second and the third places alternately. Generally, the correlation coefficients between BKE and HHKE were significant negative and stronger in case of athlete K than in case of athlete H. In order to increase the HHKE in this phase, first the athlete has to reduce the RLKE and LTOKE that will reduce subsequently the total BKE, which is associated negatively with the HHKE. Second, the athlete has to work effectively with LL. Interestingly, the RLKE and LLKE had a direct and contrast effect on HHKE.

**Release ($LP_4$- R):** This study illustrated that in order to increase the HHKE and to achieve a good distance, the body has to decrease the movement as much as possible and the direction of work has to be focused on (X) and to avoid the acceleration of the HH vertically. In addition, athlete H used the left side of body to break down the body, while athlete K used the head and the left arm to reduce the body movement at the release phase. Furthermore, they continue accelerating the Hammer with the right arm.

During the try to find out a specific group of body segments that interact to achieve a better distance, The contrast between the linear correlation and contribution percentage on one side and the stepwise regression on the other side may be resulted from the nature of the analysis where the stepwise tests the internal-correlation among the inputs (independent variables) and the output (dependent variable). Judging for one side over the other require further studies with big sample.

Finally, the higher the value of the BKE and the higher the value of HHKE were, and the higher the difference between the two values, the bigger the amount kinetic energy transferred to the hammer. This also could be noticed from the pattern of athlete movement after releasing hammer and the balance.

## 6.3 Discussion and conclusion of MS results:

This discussion will revolve around five main points, which are the main criteria to judge the reliability and validity of the designed measurement system to be used as a competent and eligible unit. These five, in my point of view, are the outlook of the curves comparing with the MA output, the accuracy of the values, the sensitivity of the unit to measure different performance levels, the effect of the impact on the signals, and how is the system fast enough to feedback the thrower with valuable variables.

In the currentstudy, the similarity between curves in each figure as mentioned in the results reveals that the MS is capable of representing the performance and the synchronizing of the variables with the support phases and HP/LP positions of the hammer head. This similarity is not only between the used methods, but also as appears to produce similar results to Murofushi et .al (2005) and (2007), Ohta et al. (2010).

On the other hand, the signals of MS looked smoother than the output of MA with exception of the angular velocity output. As for the other variables (force and acceleration), the fluctuations and their features are mostly alike for the two methods. The slight non-synchronization between the beginnings and the ends of the increment and decrement phases of the angular velocity for each the two methods was one of the essential features indisputably, which would be cleared obviously later.

The variables values were mostly identical in the strain force case. That reflects the validity of the calibrating method for SFS sensor (see chapter three), at the same time, it shows how the calculations to determine the start frame of synchronization between the two methods accurate were, as well as converting the frequency to be 300 instead of 1952 data/s to match the MA frequency. That all serve as evidence on the MA data accuracy or high validity. Meanwhile, there was a variation between the values of the MS output and MA, which ranges between 1.13 and 140 m/s² since the small values were for MS. The difference and the non-synchronize in case of MS and MA angular velocities may be due to single or both of the two following reasons: first, the equations (12 and 13) to calculate the angular velocity from MA depends on the velocity and the radius of curvature, which is mainly calculated by Simi motion program. This pattern of the change in curvature radius length is significantly different between performance levels, the better performance is more periodic and more fluctuated, because theoretically, the fluctuation of curvature radius was caused by the change of concentric acceleration which generated by athlete (Lee et al., 2000). Second, the method of calibrating gyro and accelerometers is not enough and may be needs modifications in the future work.

The devise has proved its eligibility to sense various throwing levels, as it's clearly seen the values differences between the best throw (K2) and the other throws ( H1 and K3). Therefore, this device enables the user to make the possible comparisons between the individual performances simply and obviously. In addition, the resulted resistance of this handmade devise was tested. It gave a good indication for its persistence in most of mounted sensors on the chips against the hard impacts towards the curtains. It signifys that the sensors did not produce more signal noises in the last throws than in the first throw.

Finally, the measurement devise (MS) could be easily used by the coaches and throwers, if there is a complete calculation software. This can facilitates a quick feedback with enough variable of interests, at the same time comparing the throws in a few minutes after performing.

This study might benefit the future works on providing accurate output data from accelerometer and gyros, and it can work on integrated software at the same time.

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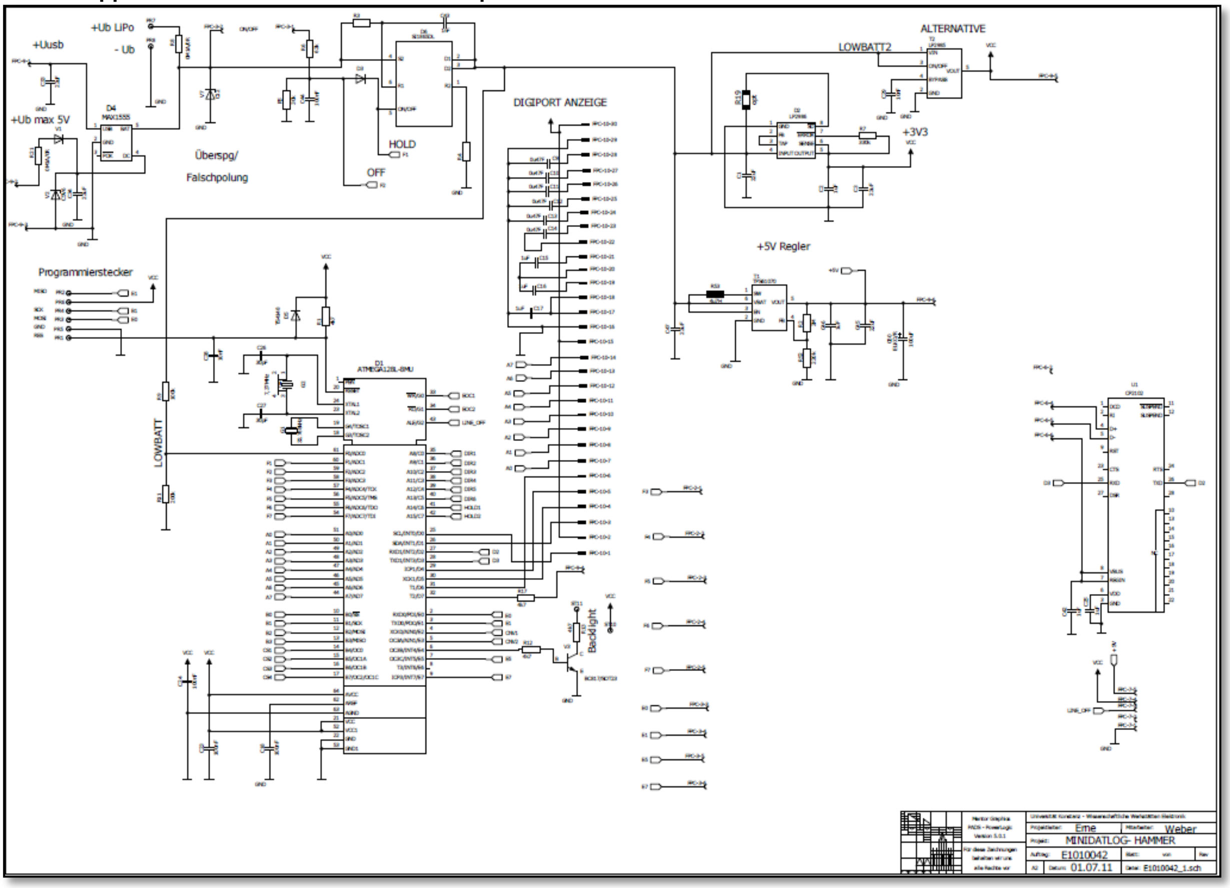
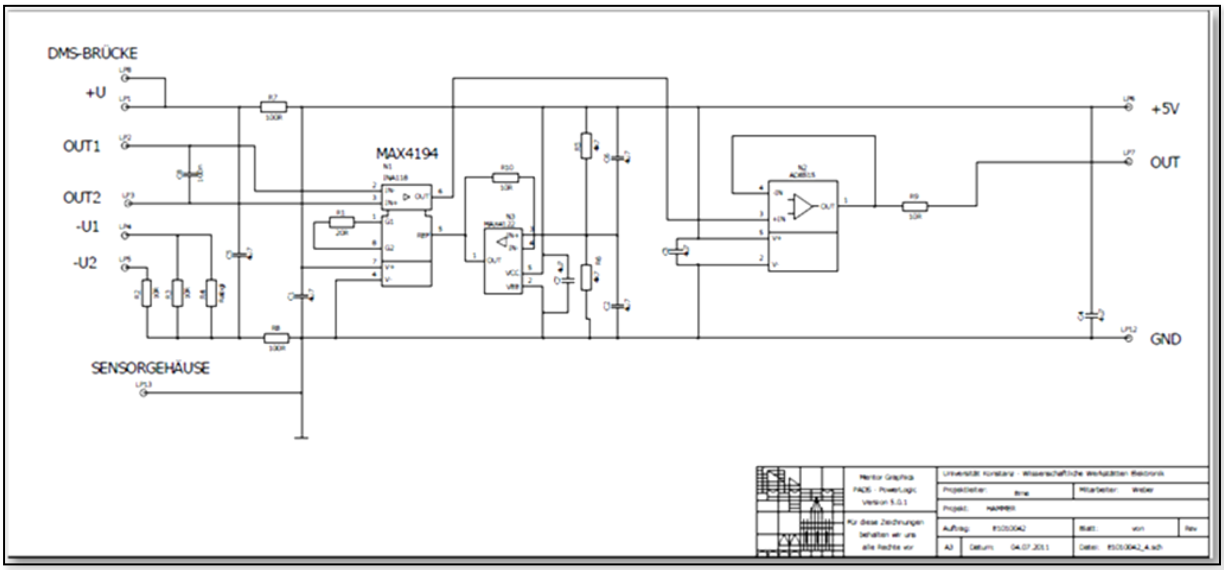
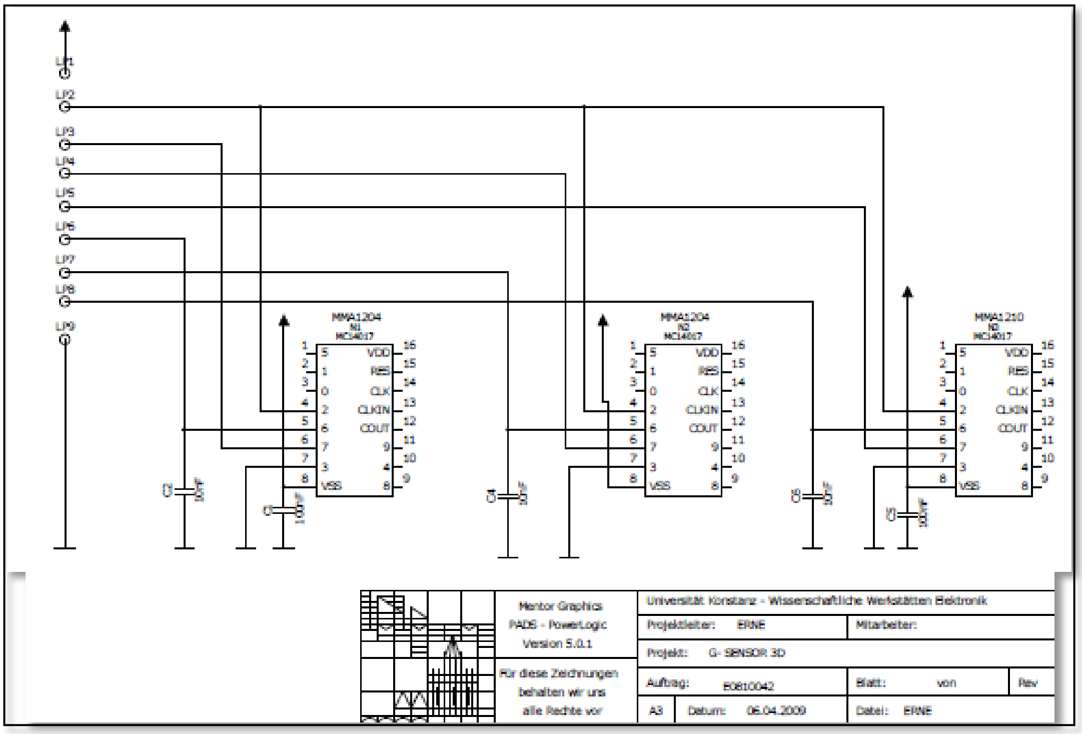
# 7 Appendices

## 7.1 Electronic details of the MS chip.

**App 1. Electronic details of the MS chip**





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LP3
LP4
LP5
LP6
LP7
LP8
LP9
MMA1204
N1
MC14017
MMA1204
N2
MC14017
MMA1210
N3
MC14017
VDD
RES
CLK
CLKIN
COUT
VSS
Mentor Graphics
PADS - PowerLogic
Version 5.0.1
Für diese Zeichnungen
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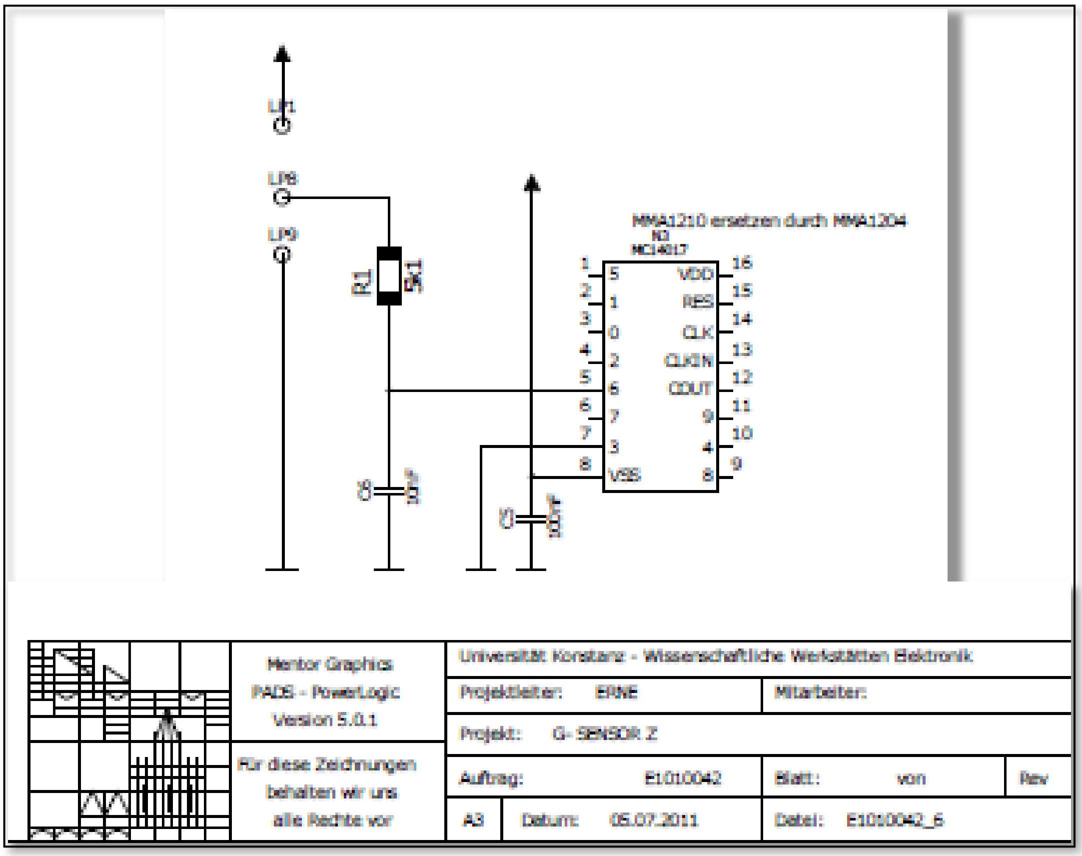
Universität Konstanz - Wissenschaftliche Werkstätten Elektronik
Projektleiter: ERNE
Mitarbeiter:
Projekt: G-SENSOR 3D
Auftrag: E0810042
Blatt: von
Rev
A3
Datum: 06.04.2009
Datei: ERNE

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LP9
R1
5k1
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N3
MC14017
VDD
RES
CLK
CLKIN
COUT
VSS
C6
10uF
C5
100nF
Mentor Graphics
PADS - PowerLogic
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Projektleiter: ERNE
Mitarbeiter:
Projekt: G-SENSOR Z
Auftrag: E1010042
Blatt: von
Rev
A3
Datum: 05.07.2011
Datei: E1010042_6

## 7.2 The relationship between kenitic energy of the body segments and both of the the Body kinetic Energy (BKE) and Hammer Head kinetic energy (HHKE).

**App 2. The linear correlation coefficients between HKE with each of BKE and HHKE through the LP-HP, SS, DS, and HP-LP phases for both throwers**

| | | Correleation between HKE and BKE | | | | | Correleation between HKE and HHKE | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Entry | 1 | 2 | 3 | 4 | Entry | 1 | 2 | 3 | 4 |
| H1 | LP-HP | 0,47** | 0,79** | 0,25** | -0,18ns | 0,98** | -0,48** | -0,69** | -0,24* | -0,29* | -0,85** |
| | SS | | -0,89** | 0,11ns | 0,15ns | 0,11ns | | 0,87** | -0,37** | -0,91** | -0,88** |
| | DS | - | 0,27ns | -0,68** | -0,03ns | 0,57** | | -0,81** | -0,52** | 0,63** | 0,50** |
| | HP-LP | | -0,56** | -0,77** | -0,57** | -0,36** | | 0,97** | 0,90** | 0,75** | 0,87** |
| | LP-R | | | | | 0,98** | | | | | -0,83** |
| H3 | LP-HP | -0,13ns | -0,58** | -0,04ns | -0,19ns | 0,99** | 0,15ns | -0,62** | -0,51** | -0,59** | -0,73** |
| | SS | | -0,34** | -0,37** | 0,67** | 0,44** | | -0,13** | -0,65** | -0,80** | -0,91** |
| | DS | | -0,71** | 0,71** | 0,58** | -0,62** | | 0,36** | 0,54** | 0,43** | 0,26ns |
| | HP-LP | | -0,73** | -0,33** | 0,07ns | 0,59** | | 0,81** | 0,95** | 0,48** | 0,86** |
| | LP-R | | | | | 1,00** | | | | | -0,87** |
| H4 | LP-HP | -0,28* | 0,03ns | -0,37** | -0,72** | 0,97** | -0,93** | -0,93** | -0,89** | -0,47** | -0,67** |
| | SS | | -0,44** | 0,25* | 0,79** | 0,25* | | 0,75** | 0,03ns | -0,59** | -0,45** |
| | DS | | 0,32** | 0,28* | 0,35** | 0,01ns | | -0,93** | -0,90** | -0,89** | 0,18ns |
| | HP-LP | | -0,80** | -0,85** | -0,18ns | -0,91** | | 0,94** | 0,95** | 0,86** | 0,95** |
| | LP-R | | | | | 0,98** | | | | | -0,70** |
| H5 | LP-HP | -0,29** | -0,02ns | 0,24* | 0,17ns | 0,96** | 0,13ns | -0,66** | -0,22ns | -0,51** | -0,93** |
| | SS | | -0,55** | -0,34** | 0,88** | 0,87** | | 0,53** | -0,51** | -0,89** | -0,92** |
| | DS | | 0,19** | 0,92** | 0,73** | 0,42** | | -0,53** | 0,11ns | -0,23ns | 0,37** |
| | HP-LP | | -0,23* | -0,51** | -0,48** | -0,91** | | 0,93** | 0,83** | 0,41** | 0,97** |
| | LP-R | | | | | 0,95** | | | | | -0,90** |
| K2 | LP-HP | 0,82** | 0,03ns | 0,24* | -0,29* | 0,99** | 0,03ns | -0,95** | -0,61** | -0,54** | -1,00** |
| | SS | | 0,06** | -0,23ns | 0,39** | 0,79** | | 0,43** | -0,31** | -0,55** | -0,61** |
| | DS | | 0,09ns | 0,34** | 0,72** | 0,81** | | -0,81** | 0,60** | -0,37** | -0,58** |
| | HP-LP | | -0,67** | -0,21ns | 0,05ns | 0,72** | | 0,92** | 0,87** | 0,94** | 0,98** |
| | LP-R | | | | | 0,99** | | | | | -1,00** |
| K3 | LP-HP | 0,85** | 0,79** | 0,25* | 0,13ns | 1,00** | -0,52** | -0,87** | -0,62** | -0,09ns | -0,88** |
| | SS | | -0,61** | 0,29** | 0,63** | 0,75** | | 0,74** | 0,38** | -0,30** | -0,73** |
| | DS | | -0,32** | -0,72** | -0,09ns | 0,65** | | -0,78** | -0,83** | -0,59** | -0,22ns |
| | HP-LP | | -0,64** | -0,87** | -0,83** | -0,31** | | 0,96** | 0,97** | 0,96** | 0,82** |
| | LP-R | | | | | 1,00** | | | | | -0,95** |
| K6 | LP-HP | 0,99** | 0,59** | -0,34** | -0,57** | 1,00** | -0,67** | -0,95** | -0,48** | -0,07ns | -0,93** |
| | SS | | -0,66** | -0,22* | -0,09ns | -0,11ns | | 0,51** | -0,01ns | -0,69** | -0,74** |
| | DS | | -0,74** | 0,09ns | -0,50** | 0,95** | | -0,98** | -0,90** | -0,87** | -0,65** |
| | HP-LP | | -0,81** | -0,78** | -0,89** | -0,92** | | 0,94** | 0,94** | 0,95** | 0,94** |
| | LP-R | | | | | 1,00** | | | | | -0,97** |

*, ** significant and highly significant at significance levels 0.05 and 0.01 respectively

**App 3. The linear correlation coefficients between UTO KE with each of BKE and HHKE through the LP-HP, SS, DS, and HP-LP phases for both throwers**

| | | Correleation between UTOKE and BKE | | | | | Correleation between UTOKE and HHKE | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Entry | 1 | 2 | 3 | 4 | Entry | 1 | 2 | 3 | 4 |
| H1 | LP-HP | -0,08ns | 0,59** | 0,09ns | -0,32** | 1,00** | -0,57** | -0,70** | -0,36** | -0,45** | -0,92** |
| | SS | | -0,76** | 0,69** | 0,53** | 0,22ns | | 0,63** | -0,67** | -0,71** | -0,83** |
| | DS | | 0,13ns | -0,70** | -0,38** | 0,64** | | -0,86** | -0,32** | 0,76** | 0,36** |
| | HP-LP | | -0,18ns | 0,25* | 0,15ns | -0,16ns | | 0,78** | 0,13ns | 0,57** | 0,85** |
| | LP-R | | | | | 1,00** | | | | | -0,93** |
| H3 | LP-HP | -0,67** | -0,81** | -0,28* | -0,29ns | 0,99** | -0,08ns | -0,80** | -0,46** | -0,61** | -0,74** |
| | SS | | -0,66** | -0,15ns | 0,87** | 0,80** | | -0,23** | -0,74** | -0,79** | -0,90** |
| | DS | | -0,87** | 0,36** | 0,36** | -0,48** | | 0,20ns | 0,54** | 0,68** | 0,12ns |
| | HP-LP | | -0,52** | -0,07ns | 0,79** | 0,58** | | 0,80** | 0,78** | -0,13ns | 0,10ns |
| | LP-R | | | | | 1,00** | | | | | -0,85** |
| H4 | LP-HP | 0,25* | 0,09ns | -0,49** | -0,70** | 1,00** | -0,17ns | -0,75** | -0,83** | -0,39** | -0,85** |
| | SS | | 0,19* | 0,42** | 0,85** | 0,70** | | 0,34** | -0,05ns | -0,67** | -0,83** |
| | DS | | 0,19ns | 0,09ns | 0,23ns | 0,55** | | -0,78** | -0,90** | -0,93** | -0,45** |
| | HP-LP | | -0,44** | -0,79** | 0,10ns | -0,20ns | | 0,78** | 0,72** | 0,01ns | 0,23ns |
| | LP-R | | | | | 1,00** | | | | | -0,87** |
| H5 | LP-HP | -0,29** | -0,37** | -0,19ns | 0,09** | 0,99** | -0,19ns | -0,89** | -0,17ns | -0,40** | -0,92** |
| | SS | | 0,17ns | 0,04ns | 0,91** | 0,91** | | -0,38** | -0,60** | -0,98** | -0,90** |
| | DS | | -0,03ns | 0,71** | 0,53** | 0,15ns | | -0,30** | 0,30* | 0,27* | 0,63** |
| | HP-LP | | 0,46** | -0,04ns | -0,18ns | -0,54** | | 0,58** | 0,87** | 0,29* | 0,80** |
| | LP-R | | | | | 0,99** | | | | | -0,86** |
| K2 | LP-HP | -0,29** | -0,34** | 0,42** | -0,02ns | 0,99** | -0,21ns | -0,85** | -0,57** | -0,63** | -0,97** |
| | SS | | 0,34** | -0,31** | 0,66** | 0,87** | | -0,15ns | -0,32** | -0,80** | -0,88** |
| | DS | | 0,44** | 0,81** | 0,72** | 0,55** | | -0,65** | -0,15ns | -0,42** | -0,32* |
| | HP-LP | | -0,21* | -0,35** | 0,56** | 0,22ns | | 0,60** | 0,21ns | 0,49** | 0,69** |
| | LP-R | | | | | 0,86** | | | | | -0,72** |
| K3 | LP-HP | 0,75** | 0,31** | 0,46** | 0,62** | 1,00** | -0,90** | -0,56** | -0,37** | -0,47** | -0,89** |
| | SS | | -0,10ns | 0,50** | 0,92** | 0,92** | | 0,19ns | 0,15ns | -0,80** | -0,66** |
| | DS | | 0,04ns | 0,25ns | 0,53** | 0,93** | | -0,51** | -0,40** | -0,92** | -0,68** |
| | HP-LP | | -0,34** | -0,85** | -0,22** | -0,29* | | 0,81** | 0,97** | 0,41** | 0,89** |
| | LP-R | | | | | 1,00** | | | | | -0,96** |
| K6 | LP-HP | 0,20ns | -0,22* | -0,14ns | -0,45** | 0,99** | -0,84** | -0,74** | -0,64** | -0,14ns | -0,93** |
| | SS | | -0,55** | 0,00 | 0,21ns | 0,31** | | 0,13ns | -0,38** | -0,92** | -0,95** |
| | DS | | -0,82** | -0,15ns | -0,56** | 0,83** | | -0,64** | -0,77** | -0,23ns | -0,39** |
| | HP-LP | | -0,79** | 0,00ns | -0,13ns | -0,51** | | 0,74** | 0,27* | 0,00 | 0,76** |
| | LP-R | | | | | 1,00** | | | | | -0,97** |

*, ** significant and highly significant at significance levels 0.05 and 0.01 respectively

**App 4. The linear correlation coefficients between LTOKE with each of BKE and HHKE through the the LP-HP, SS, DS, and HP-LP phases for both throwers**

| | | Correleation between LTOKE and BKE | | | | | Correleation between LTOKE and HHKE | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Entry | 1 | 2 | 3 | 4 | Entry | 1 | 2 | 3 | 4 |
| H1 | LP-HP | 0,70** | 0,65** | 0,37** | -0,22ns | 0,98** | -0,34** | -0,76** | -0,29* | -0,62** | -0,97** |
| | SS | | -0,91** | 0,36** | 0,30** | 0,07ns | | 0,63** | -0,47** | -0,89** | -0,92** |
| | DS | | 0,23* | -0,47** | 0,29* | 0,75** | | -0,84** | -0,65** | 0,19ns | -0,79** |
| | HP-LP | | -0,65** | -0,24** | 0,63** | 0,19ns | | 0,74** | 0,51** | -0,61** | -0,38** |
| | LP-R | | | | | 0,98** | | | | | -0,97** |
| H3 | LP-HP | 0,97** | -0,29** | -0,08ns | 0,04ns | 0,94** | -0,54** | -0,31* | -0,48** | -0,48** | -0,85** |
| | SS | | 0,05** | -0,21ns | 0,84** | 0,86** | | -0,05** | -0,67** | -0,73** | -0,78** |
| | DS | | -0,31** | 0,85** | 0,86** | 0,93** | | 0,01ns | 0,41** | 0,54** | 0,11ns |
| | HP-LP | | -0,63** | 0,00ns | 0,96** | 0,09ns | | 0,53** | 0,58** | -0,05ns | -0,45** |
| | LP-R | | | | | 0,96** | | | | | -0,94** |
| H4 | LP-HP | 0,94** | 0,19ns | -0,16ns | -0,28* | 1,00** | 0,17ns | -0,83** | -0,97** | -0,77** | -0,80** |
| | SS | | -0,09ns | 0,50** | 0,90** | 0,68** | | 0,51** | -0,19ns | -0,58** | -0,84** |
| | DS | | 0,23* | 0,76** | 0,70** | 0,97** | | -0,96** | -0,87** | -0,88** | -0,96** |
| | HP-LP | | -0,43** | 0,41** | 0,85** | 0,81** | | 0,20ns | 0,05ns | 0,03ns | -0,69** |
| | LP-R | | | | | 1,00** | | | | | -0,79** |
| H5 | LP-HP | 0,79** | 0,29** | 0,14ns | 0,19ns | 0,97** | -0,58** | -0,47** | -0,25* | -0,42** | -0,95** |
| | SS | | 0,17ns | 0,26* | 0,86** | 0,92** | | 0,04ns | -0,71** | -0,96** | -0,98** |
| | DS | | 0,19ns | 0,87** | 0,93** | 0,90** | | -0,63** | -0,12ns | 0,01ns | -0,66** |
| | HP-LP | | 0,64** | 0,77** | 0,25* | 0,33** | | 0,26** | -0,13ns | 0,26* | -0,14ns |
| | LP-R | | | | | 0,99** | | | | | -0,87** |
| K2 | LP-HP | 0,45** | 0,03ns | 0,77** | 0,17ns | 0,99** | -0,36** | -0,92** | -0,52** | -0,67** | -0,99** |
| | SS | | 0,43** | -0,10ns | 0,82** | 0,82** | | -0,10ns | -0,48** | -0,80** | -0,86** |
| | DS | | 0,28* | 0,47** | 0,85** | 0,93** | | -0,64** | 0,36** | -0,52** | -0,88** |
| | HP-LP | | -0,26** | -0,65** | 0,72** | 0,47** | | 0,53** | -0,36** | 0,35** | 0,32** |
| | LP-R | | | | | 1,00** | | | | | -0,98** |
| K3 | LP-HP | 0,96** | 0,77** | 0,41** | 0,66** | 0,96** | -0,74** | -0,87** | -0,49** | -0,43** | -0,79** |
| | SS | | -0,03ns | 0,73** | 0,98** | 0,89** | | 0,03ns | -0,07ns | -0,82** | -0,65** |
| | DS | | -0,28* | -0,17ns | 0,81** | 0,82** | | -0,83** | -0,76** | -0,90** | -0,68** |
| | HP-LP | | -0,53** | 0,06ns | 0,77** | 0,42** | | 0,62** | 0,40** | -0,50** | 0,29* |
| | LP-R | | | | | 0,97** | | | | | -0,90** |
| K6 | LP-HP | 0,79** | 0,34** | 0,46** | -0,18ns | 0,99** | -0,73** | -0,96** | -0,95** | -0,35** | -0,85** |
| | SS | | -0,13ns | 0,04ns | 0,68** | 0,58** | | 0,02ns | -0,23* | -0,94** | -0,86** |
| | DS | | -0,69** | 0,11ns | -0,25ns | 0,88** | | -0,95** | -0,93** | -0,46** | -0,71** |
| | HP-LP | | -0,18ns | -0,23ns | 0,92** | -0,45** | | 0,44** | 0,19ns | -0,60** | 0,29* |
| | LP-R | | | | | 1,00** | | | | | -0,94** |

*, ** significant and highly significant at significance levels 0.05 and 0.01 respectively

**App 5. The linear correlation coefficients between RAKE with each of BKE and HHKE through the acceleration and deceleration phases for both throwers**

| Trials | Phases | Correleation between RAKE and BKE | | | | | Correleation between RAKE and HHKE | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Entry | 1 | 2 | 3 | 4 | Entry | 1 | 2 | 3 | 4 |
| H1 | LP-HP | 0,41** | -0,09ns | 0,70** | 0,62** | -0,98** | 0,27** | 0,58** | 0,43** | 0,67** | 0,85** |
| | SS | | 0,92** | 0,15ns | -0,01ns | -0,10ns | | -0,87** | -0,13ns | 0,96** | 0,87** |
| | DS | | 0,03ns | 0,71** | 0,42** | -0,69** | | 0,87** | 0,55** | -0,78** | -0,31* |
| | HP-LP | | 0,91** | 0,88** | 0,72** | 0,43** | | -0,64** | -0,94** | -0,77** | -0,75** |
| | LP-R | | | | | -0,98** | | | | | 0,83** |
| H3 | LP-HP | 0,60** | 0,99** | 0,89** | 0,89** | -0,96** | -0,78** | 0,67** | 0,11ns | 0,38** | 0,60** |
| | SS | | 0,60** | 0,57** | 0,39** | 0,33** | | 0,09** | 0,22** | 0,19ns | 0,40** |
| | DS | | 0,84** | -0,28* | -0,29* | -0,54** | | 0,46** | -0,02ns | -0,24ns | -0,32* |
| | HP-LP | | 0,75** | 0,47** | 0,83** | -0,10ns | | 0,32** | -0,69** | -0,72** | -0,67** |
| | LP-R | | | | | -0,98** | | | | | 0,80** |
| H4 | LP-HP | -0,08ns | 0,70** | 0,81** | 0,93** | -1,00** | -0,41** | 0,74** | 0,58** | 0,03ns | 0,88** |
| | SS | | 0,48** | -0,24* | -0,53** | 0,03ns | | -0,88** | 0,12ns | 0,32** | 0,21ns |
| | DS | | 0,06ns | 0,28* | 0,47** | -0,86** | | 0,60** | 0,64** | 0,59** | 0,79** |
| | HP-LP | | 0,67** | 0,91** | 0,74** | 0,94** | | -0,60** | -0,65** | -0,82** | -0,95** |
| | LP-R | | | | | -0,99** | | | | | 0,88** |
| H5 | LP-HP | 0,17ns | 0,61** | 0,34** | 0,52** | -1,00** | -0,60** | 0,89** | 0,25* | -0,11ns | 0,92** |
| | SS | | 0,51** | 0,19ns | -0,72** | -0,59** | | -0,70** | 0,31** | 0,83** | 0,72** |
| | DS | | 0,15ns | -0,69** | -0,39** | -0,83** | | 0,51** | -0,46** | -0,19ns | 0,02ns |
| | HP-LP | | 0,62** | 0,34** | 0,75** | 0,85** | | -0,49** | -0,93** | -0,93** | -0,97** |
| | LP-R | | | | | -0,99** | | | | | 0,89** |
| K2 | LP-HP | 0,24* | 0,46** | -0,03ns | 0,24ns | -0,99** | 0,14ns | 0,87** | 0,54** | 0,43** | 0,97** |
| | SS | | 0,17ns | 0,36** | -0,31** | -0,43** | | -0,55** | -0,29** | -0,01ns | 0,14ns |
| | DS | | -0,05ns | -0,42** | -0,60** | -0,92** | | 0,80** | -0,56** | 0,18ns | 0,70** |
| | HP-LP | | 0,51** | 0,06ns | 0,03ns | -0,66** | | -0,95** | -0,91** | -0,95** | -0,98** |
| | LP-R | | | | | -0,97** | | | | | 0,90** |
| K3 | LP-HP | -0,33** | 0,36** | 0,00ns | -0,06ns | -0,99** | -0,03ns | -0,13ns | 0,33** | 0,06ns | 0,94** |
| | SS | | 0,57** | 0,06ns | -0,34** | -0,41** | | -0,87** | -0,80** | -0,01ns | -0,06ns |
| | DS | | 0,35** | 0,66** | 0,21ns | -0,58** | | 0,83** | 0,78** | 0,51** | 0,30* |
| | HP-LP | | 0,83** | 0,74** | 0,84** | 0,44** | | -0,92** | -0,97** | -0,97** | -0,94** |
| | LP-R | | | | | -0,98** | | | | | 0,97** |
| K6 | LP-HP | 0,18ns | 0,21ns | 0,51** | 0,55** | -0,93** | -0,40** | 0,76** | 0,31** | -0,02ns | 0,97** |
| | SS | | 0,69** | 0,15ns | -0,45** | -0,20ns | | -0,94** | -0,35** | 0,80** | 0,50** |
| | DS | | 0,81** | 0,08ns | 0,59** | -0,90** | | 0,96** | 0,88** | 0,64** | 0,67** |
| | HP-LP | | 0,78** | 0,81** | 0,57** | 0,78** | | -0,98** | -0,92** | -0,89** | -0,96** |
| | LP-R | | | | | -0,87** | | | | | 0,90** |

*, ** significant and highly significant at significance levels 0.05 and 0.01 respectively

**App 6. The linear correlation coefficients between LAKE with each of BKE and HHKE through the LP-HP, SS, DS, and HP-LP phases for both throwers**

| Trials | Phases | Correleation between LAKE and BKE | | | | | Correleation between LAKE and HHKE | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Entry | 1 | 2 | 3 | 4 | Entry | 1 | 2 | 3 | 4 |
| H1 | LP-HP | -0,77** | -0,90** | -0,84** | -0,82** | 0,85** | -0,40** | 0,30** | -0,07ns | -0,40** | -0,93** |
| | SS | | -0,41** | -0,76** | -0,20ns | -0,75** | | 0,11ns | 0,64** | 0,14ns | 0,27* |
| | DS | | -0,55** | 0,34** | -0,19ns | -0,51** | | 0,60** | 0,65** | -0,45** | 0,31* |
| | HP-LP | | 0,03ns | -0,89** | -0,46** | -0,37** | | 0,21* | 0,97** | 0,48** | 0,85** |
| | LP-R | | | | | 0,89** | | | | | -0,98** |
| H3 | LP-HP | -0,85** | -0,18ns | -0,68** | -0,87** | 0,26ns | 0,49** | 0,27* | 0,78** | 0,24ns | -0,10ns |
| | SS | | -0,17** | 0,15ns | -0,60** | -0,45** | | 0,37** | 0,77** | 0,94** | 0,84** |
| | DS | | 0,43** | -0,87** | -0,95** | -0,63** | | 0,06ns | -0,27* | -0,36** | -0,37** |
| | HP-LP | | 0,34** | 0,36** | -0,52** | 0,42** | | 0,51** | 0,59** | 0,75** | 0,70** |
| | LP-R | | | | | 0,05ns | | | | | 0,16ns |
| H4 | LP-HP | -0,57** | -0,59** | -0,76** | -0,35** | 0,66** | -0,15ns | 0,64** | 0,57** | 0,70** | -0,40* |
| | SS | | -0,14ns | -0,86** | -0,31** | -0,62** | | -0,01ns | 0,94** | 0,91** | 0,85** |
| | DS | | -0,13ns | -0,87** | -0,61** | -0,56** | | 0,86** | 0,68** | 0,26* | 0,75** |
| | HP-LP | | -0,48** | -0,95** | -0,55** | -0,85** | | 0,81** | 0,90** | 0,88** | 0,95** |
| | LP-R | | | | | 0,85** | | | | | -0,70** |
| H5 | LP-HP | -0,83** | -0,66** | -0,87** | -0,73** | 0,94** | 0,46** | -0,40** | 0,49** | 0,56** | -0,73** |
| | SS | | -0,26** | -0,17ns | -0,61** | -0,34** | | -0,14ns | 0,70** | 0,51** | 0,25* |
| | DS | | -0,13ns | -0,78** | -0,84** | -0,44** | | 0,60** | 0,30* | 0,06ns | 0,75** |
| | HP-LP | | 0,28* | -0,53** | -0,85** | -0,66** | | 0,72** | 0,86** | 0,88** | 0,77** |
| | LP-R | | | | | 0,85** | | | | | -0,44** |
| K2 | LP-HP | -0,71** | -0,77** | -0,65** | -0,77** | 0,97** | -0,01ns | -0,24* | -0,24* | -0,04ns | -0,96** |
| | SS | | -0,66** | -0,60** | -0,34** | -0,07ns | | 0,18ns | -0,10ns | 0,09ns | 0,43** |
| | DS | | -0,03ns | 0,62** | -0,28* | -0,42** | | 0,26* | -0,61** | 0,18ns | 0,57** |
| | HP-LP | | -0,74** | 0,32** | 0,04ns | 0,44** | | 0,39** | 0,70** | 0,67** | 0,80** |
| | LP-R | | | | | 0,59** | | | | | -0,40** |
| K3 | LP-HP | -0,81** | -0,85** | -0,59** | -0,27* | 0,94** | 0,15ns | 0,62** | 0,75** | 0,56** | -0,84** |
| | SS | | -0,38** | -0,30** | -0,20ns | -0,45** | | -0,10ns | 0,22ns | 0,25* | 0,20ns |
| | DS | | 0,69** | 0,85** | 0,29* | -0,41** | | 0,88** | 0,82** | -0,04ns | 0,75** |
| | HP-LP | | 0,63** | -0,53** | -0,35** | -0,63** | | -0,46** | 0,06ns | 0,13ns | 0,56** |
| | LP-R | | | | | 0,84** | | | | | -0,83** |
| K6 | LP-HP | -0,67** | -0,95** | -0,99** | -0,97** | 0,73** | -0,09ns | 0,36** | 0,65** | 0,63** | -0,40** |
| | SS | | -0,48** | -0,70** | -0,89** | -0,84** | | -0,24* | 0,23* | 0,23* | 0,08ns |
| | DS | | 0,23* | -0,64** | -0,29* | 0,05ns | | 0,78** | 0,80** | 0,66** | 0,83** |
| | HP-LP | | -0,47** | -0,48** | -0,94** | -0,64** | | -0,03ns | 0,56** | 0,79** | 0,84** |
| | LP-R | | | | | 0,86** | | | | | -0,82** |

*, ** significant and highly significant at significance levels 0.05 and 0.01 respectively

**App 7. The linear correlation coefficients between RLKE with each of BKE and HHKE through the the LP-HP, SS, DS, and HP-LP phases for both throwers**

| Trials | phases | Correleation between RLKE and BKE | | | | | Correleation between RLKE and HHKE | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Entry | 1 | 2 | 3 | 4 | Entry | 1 | 2 | 3 | 4 |
| H1 | LP-HP | 0,89** | 0,92** | 0,95** | 0,95** | 0,86** | 0,11ns | 0,06ns | 0,19ns | 0,61** | -0,60** |
| | SS | | 0,98** | 0,61** | 0,41** | 0,67** | | -0,76** | -0,30** | 0,79** | 0,71** |
| | DS | | 0,35** | 0,80** | 0,23ns | 0,65** | | 0,75** | 0,32** | -0,36** | 0,25ns |
| | HP-LP | | 0,87** | 0,94** | 0,70** | 0,38** | | -0,89** | -0,96** | -0,47** | -0,41** |
| | LP-R | | | | | 0,86** | | | | | -0,59** |
| H3 | LP-HP | 1,00** | 0,98** | 0,97** | 0,99** | 0,39* | -0,69** | 0,53** | -0,14ns | 0,02ns | 0,24ns |
| | SS | | 0,86** | 0,84** | 0,54** | 0,49** | | -0,15** | 0,07ns | -0,07ns | -0,01ns |
| | DS | | 0,95** | 0,08ns | 0,25* | 0,79** | | -0,07ns | -0,08ns | -0,20ns | -0,18ns |
| | HP-LP | | 0,96** | 0,79** | 0,85** | -0,29* | | -0,51** | -0,65** | -0,69** | -0,78** |
| | LP-R | | | | | -0,03ns | | | | | 0,34* |
| H4 | LP-HP | 0,98** | 0,98** | 0,99** | 0,97** | 0,80** | 0,57** | 0,32** | 0,16ns | -0,24* | -0,99** |
| | SS | | 0,78** | 0,38** | -0,16ns | 0,23* | | -0,79** | -0,61** | -0,21ns | -0,09ns |
| | DS | | 0,38** | 0,47** | 0,38** | 0,90** | | 0,64** | 0,23ns | 0,57** | -0,94** |
| | HP-LP | | 0,95** | 0,78** | 0,48** | 0,90** | | -0,91** | -0,94** | -0,95** | -0,96** |
| | LP-R | | | | | 0,76** | | | | | -0,98** |
| H5 | LP-HP | 0,93** | 0,95** | 0,93** | 0,88** | 0,86** | -0,61** | 0,75** | -0,38** | -0,57** | -0,64** |
| | SS | | 0,84** | 0,74** | 0,10ns | 0,22ns | | -0,64** | 0,10ns | 0,28** | 0,02ns |
| | DS | | 0,35** | -0,37** | -0,01ns | 0,96** | | 0,69** | 0,06ns | 0,23ns | -0,63** |
| | HP-LP | | 0,71** | 0,88** | 0,80** | 0,78** | | -0,87** | -0,58** | -0,69** | -0,76** |
| | LP-R | | | | | 0,76** | | | | | -0,42** |
| K2 | LP-HP | 0,97** | 0,93** | 0,52** | 0,77** | 0,72** | -0,03ns | 0,46** | 0,33** | 0,17ns | -0,66** |
| | SS | | 0,61** | 0,68** | 0,04ns | -0,28* | | -0,51** | -0,03ns | 0,37** | 0,24* |
| | DS | | 0,05ns | -0,39** | -0,53** | 0,85** | | 0,89** | -0,49** | 0,36** | -0,92** |
| | HP-LP | | 0,90** | 0,44** | 0,15ns | -0,78** | | -0,73** | -0,67** | -0,93** | -0,90** |
| | LP-R | | | | | 0,18ns | | | | | 0,01ns |
| K3 | LP-HP | 0,72** | 0,73** | 0,48** | 0,24ns | 0,93** | -0,10ns | -0,49** | -0,42** | -0,43** | -0,82** |
| | SS | | 0,71** | 0,17ns | -0,11ns | -0,32** | | -0,57** | -0,55** | -0,18ns | 0,47** |
| | DS | | 0,23* | 0,41** | -0,07ns | 0,75** | | 0,75** | 0,78** | 0,69** | -0,81** |
| | HP-LP | | 0,94** | 0,92** | 0,83** | 0,45** | | -0,93** | -0,80** | -0,89** | -0,80** |
| | LP-R | | | | | 0,85** | | | | | -0,80** |
| K6 | LP-HP | 0,90** | 0,95** | 0,94** | 0,94** | 0,95** | -0,30** | -0,14ns | -0,37** | -0,55** | -0,96** |
| | SS | | 0,87** | 0,72** | 0,71** | 0,66** | | -0,50** | -0,35** | 0,13ns | 0,26* |
| | DS | | 0,88** | 0,25ns | 0,54** | 0,37** | | 0,89** | 0,80** | 0,47** | -0,75** |
| | HP-LP | | 0,95** | 0,90** | 0,99** | 0,96** | | -0,76** | -0,84** | -0,89** | -0,90** |
| | LP-R | | | | | 0,93** | | | | | -0,95** |

*, ** significant and highly significant at significance levels 0.05 and 0.01 respectively

**App 8. The linear correlation coefficients between LLKE with each of BKE and HHKE through the LP-HP, SS, DS, and HP-LP phases for both throwers**

| Trials | phases | Correleation between LLKE and BKE | | | | | Correleation between LLKE and HHKE | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Entry | 1 | 2 | 3 | 4 | Entry | 1 | 2 | 3 | 4 |
| H1 | LP-HP | 0,60** | -0,47** | -0,94** | -0,85** | 0,99** | -0,50** | -0,54** | -0,08ns | -0,70** | -0,88** |
| | SS | | -0,26* | 0,09ns | -0,30** | -0,72** | | 0,09ns | -0,35** | -0,63** | -0,59** |
| | DS | | -0,25* | 0,05ns | 0,91** | 0,87** | | -0,61** | 0,69** | -0,21ns | -0,20ns |
| | HP-LP | | 0,27** | -0,55** | -0,26* | -0,07ns | | 0,46** | 0,75** | 0,48** | 0,25* |
| | LP-R | | | | | 0,99** | | | | | -0,86** |
| H3 | LP-HP | 0,37** | -0,56** | -0,93** | -0,90** | 0,96** | 0,23ns | 0,07ns | 0,34** | 0,28ns | -0,64** |
| | SS | | 0,33** | -0,34** | -0,23* | -0,20ns | | 0,00ns | 0,69** | -0,07ns | -0,09ns |
| | DS | | 0,06ns | -0,07ns | 0,93** | 0,93** | | -0,01ns | 0,14ns | 0,70** | 0,30** |
| | HP-LP | | 0,60** | -0,21ns | -0,44** | 0,25ns | | 0,19ns | 0,98** | 0,87** | 0,41** |
| | LP-R | | | | | 0,97** | | | | | -0,82** |
| H4 | LP-HP | 0,52** | -0,61** | -0,94** | -0,73** | 0,98** | -0,28* | -0,18ns | 0,22ns | 0,65** | -0,90** |
| | SS | | -0,01ns | -0,29** | 0,19ns | -0,42** | | 0,37** | 0,58** | 0,44** | 0,45** |
| | DS | | 0,27* | -0,27* | 0,83** | 0,97** | | 0,23* | 0,81** | -0,03ns | -0,95** |
| | HP-LP | | -0,37** | -0,11ns | -0,04ns | -0,40** | | 0,74** | 0,58** | 0,89** | 0,56** |
| | LP-R | | | | | 0,98** | | | | | -0,89** |
| H5 | LP-HP | 0,53** | -0,89** | -0,87** | -0,79** | 0,99** | -0,60** | -0,69** | 0,35** | 0,48** | -0,89** |
| | SS | | 0,03ns | -0,65** | 0,14ns | -0,02ns | | -0,06ns | -0,02ns | -0,47** | -0,16ns |
| | DS | | -0,23** | -0,10ns | 0,35** | 0,95** | | 0,14ns | 0,37** | -0,35** | -0,60** |
| | HP-LP | | 0,62** | -0,62** | -0,59** | -0,32** | | 0,37** | 0,80** | 0,58** | 0,26* |
| | LP-R | | | | | 0,99** | | | | | -0,89** |
| K2 | LP-HP | -0,26* | -0,81** | -0,44** | -0,69** | 0,97** | 0,04ns | -0,53** | -0,19ns | -0,19ns | -0,96** |
| | SS | | 0,11ns | -0,71** | -0,17ns | 0,32** | | 0,32** | 0,23* | -0,09ns | -0,05ns |
| | DS | | -0,07ns | 0,69** | 0,38** | 0,86** | | -0,75** | 0,47** | -0,07ns | -0,87** |
| | HP-LP | | -0,66** | 0,16ns | -0,07ns | 0,84** | | 0,88** | 0,88** | 0,97** | 0,36** |
| | LP-R | | | | | 0,98** | | | | | -1,00** |
| K3 | LP-HP | 0,84** | -0,48** | -0,37** | -0,12ns | 0,92** | -0,71** | 0,26* | 0,39** | 0,32** | -1,00** |
| | SS | | 0,06ns | 0,03ns | 0,41** | 0,46** | | 0,17ns | 0,56** | -0,03ns | -0,57** |
| | DS | | 0,49** | 0,42** | 0,64** | 0,84** | | -0,12ns | -0,26* | -0,91** | -0,98** |
| | HP-LP | | -0,83** | -0,70** | -0,21ns | 0,25* | | 0,89** | 0,72** | 0,55** | 0,20ns |
| | LP-R | | | | | 0,97** | | | | | -0,99** |
| K6 | LP-HP | 0,83** | 0,20ns | 0,27* | -0,16ns | 0,98** | -0,29* | 0,40** | 0,33** | 0,67** | -0,95** |
| | SS | | 0,21* | -0,67** | -0,53** | -0,49** | | 0,54** | 0,96** | 0,95** | 0,97** |
| | DS | | -0,05ns | 0,63** | 0,39** | 0,93** | | -0,69** | -0,83** | -0,68** | -0,66** |
| | HP-LP | | -0,04ns | -0,87** | -0,79** | -0,85** | | 0,62** | 0,94** | 0,91** | 0,97** |
| | LP-R | | | | | 0,99** | | | | | -0,99** |

*, ** significant and highly significant at significance levels 0.05 and 0.01 respectively

**App 9. The linear correlation coefficients between BKE and HHKE through the LP-HP, SS, DS, and HP-LP phases for both throwers**

| Trials | | Correlation between BKE and HHKE | | | | |
|---|---|---|---|---|---|---|
| | Phases | Entry | 1 | 2 | 3 | 4 |
| H1 | LP-HP | -0,15ns | -0,27* | 0,17ns | 0,36** | -0,92** |
| | SS | | -0,83** | -0,80** | 0,02ns | 0,01ns |
| | DS | | -0,09ns | 0,44** | -0,28* | -0,30* |
| | HP-LP | | -0,63** | -0,88** | -0,44** | -0,14ns |
| | LP-R | | | | | -0,91** |
| H3 | LP-HP | -0,65** | 0,68** | -0,15ns | 0,04ns | -0,77** |
| | SS | | -0,13** | 0,02ns | -0,58** | -0,59** |
| | DS | | 0,14ns | 0,65** | 0,58** | 0,04ns |
| | HP-LP | | -0,30** | -0,12ns | -0,28* | -0,55** |
| | LP-R | | | | | -0,88** |
| H4 | LP-HP | 0,42** | 0,22* | 0,05ns | -0,21ns | -0,84** |
| | SS | | -0,67** | -0,77** | -0,49** | -0,80** |
| | DS | | -0,17ns | -0,40** | -0,39** | -0,94** |
| | HP-LP | | -0,82** | -0,81** | -0,39** | -0,93** |
| | LP-R | | | | | -0,84** |
| H5 | LP-HP | -0,75** | 0,57** | -0,42** | -0,82** | -0,91** |
| | SS | | -0,78** | -0,39** | -0,87** | -0,96** |
| | DS | | 0,53** | 0,10ns | -0,08ns | -0,55** |
| | HP-LP | | -0,42** | -0,34** | -0,63** | -0,85** |
| | LP-R | | | | | -0,83** |
| K2 | LP-HP | -0,08ns | 0,15** | -0,12ns | -0,33* | -0,99** |
| | SS | | -0,59** | -0,61** | -0,59** | -0,69** |
| | DS | | 0,28* | -0,13ns | -0,50** | -0,90** |
| | HP-LP | | -0,58** | 0,14ns | -0,14ns | 0,68** |
| | LP-R | | | | | -0,97** |
| K3 | LP-HP | -0,62** | -0,92** | -0,76** | -0,90** | -0,91** |
| | SS | | -0,76** | -0,52** | -0,84** | -0,84** |
| | DS | | 0,74** | 0,59** | -0,68** | -0,84** |
| | HP-LP | | -0,78** | -0,76** | -0,85** | -0,65** |
| | LP-R | | | | | -0,96** |
| K6 | LP-HP | -0,60** | -0,41** | -0,63** | -0,76** | -0,89** |
| | SS | | -0,62** | -0,72** | -0,57** | -0,50** |
| | DS | | 0,75** | -0,15ns | 0,26* | -0,48** |
| | HP-LP | | -0,69** | -0,81** | -0,86** | -0,82** |
| | LP-R | | | | | -0,96** |

*, ** significant and highly significant at significance levels 0.05 and 0.01 respectively

## 7.3 The contribution of the Body segments Kinetic energies (BSKE) to the Hammer Head kinetic energy (HHKE).

**App 10. The segment's Kinetic energies contribution percentages to hammer head kinetic energy during the LP-HP, SS, DS, HP-LP and Release phases for thrower H, trial 1**

| H1 | | The turns | | | | | |
|---|---|---|---|---|---|---|---|
| KE of | phases | Entry | 1 | 2 | 3 | 4 | In Y direction |
| H | LP-HP | 0,2 | 0,2 | 0,3 | 0,5 | 0,8 | |
| | SS | | 0,5 | 0,5 | 0,7 | 0,8 | 0,3 |
| | DS | | 0,4 | 0,5 | 0,9 | 1,5 | |
| | HP-LP | | 0,7 | 0,8 | 1,1 | 1,4 | |
| | LP-R | | | | | 1,0 | |
| UTO | LP-HP | 0,5 | 0,3 | 0,5 | 0,6 | 1,2 | |
| | SS | | 0,7 | 0,7 | 0,9 | 0,7 | 0,5 |
| | DS | | 0,7 | 0,8 | 1,0 | 2,1 | |
| | HP-LP | | 1,0 | 1,0 | 1,3 | 1,6 | |
| | LP-R | | | | | 1,4 | |
| LTO | LP-HP | 2,7 | 1,4 | 1,3 | 1,6 | 1,7 | |
| | SS | | 5,7 | 3,9 | 3,2 | 2,7 | 0,5 |
| | DS | | 3,4 | 2,7 | 3,0 | 3,4 | |
| | HP-LP | | 6,8 | 5,2 | 4,5 | 4,2 | |
| | LP-R | | | | | 2,1 | |
| RA | LP-HP | 3,0 | 2,6 | 2,5 | 2,4 | 2,8 | |
| | SS | | 2,6 | 2,5 | 2,7 | 2,7 | 3,5 |
| | DS | | 2,2 | 1,6 | 1,5 | 1,6 | |
| | HP-LP | | 2,0 | 2,0 | 1,9 | 1,9 | |
| | LP-R | | | | | 2,7 | |
| LA | LP-HP | 2,4 | 2,2 | 2,0 | 2,0 | 2,8 | |
| | SS | | 2,2 | 2,0 | 1,7 | 1,8 | 2,5 |
| | DS | | 2,6 | 2,4 | 2,1 | 2,6 | |
| | HP-LP | | 2,2 | 2,2 | 1,8 | 2,1 | |
| | LP-R | | | | | 2,9 | |
| RL | LP-HP | 19,0 | 8,4 | 6,6 | 6,8 | 0,8 | |
| | SS | | 14,8 | 10,1 | 7,8 | 8,3 | 0,5 |
| | DS | | 3,4 | 2,6 | 2,3 | 1,6 | |
| | HP-LP | | 5,6 | 5,8 | 4,2 | 4,3 | |
| | LP-R | | | | | 0,9 | |
| LL | LP-HP | 4,1 | 4,5 | 5,3 | 5,2 | 2,6 | |
| | SS | | 6,0 | 5,5 | 5,1 | 4,8 | 1,3 |
| | DS | | 6,4 | 6,7 | 7,1 | 5,1 | |
| | HP-LP | | 6,8 | 6,7 | 6,6 | 6,0 | |
| | LP-R | | | | | 2,9 | |

**App 11. The segment's Kinetic energies contribution percentages to hammer head kinetic energy during the LP-HP, SS, DS, HP-LP and Release phases for thrower H, trial 3**

| H3 | | The Turns | | | | | |
|---|---|---|---|---|---|---|---|
| KE of | phases | Entry | 1 | 2 | 3 | 4 | In Y direction |
| H | LP-HP | 0,1 | 0,3 | 0,5 | 0,4 | 1,4 | |
| | SS | | 0,3 | 0,6 | 0,8 | 1,0 | 0,5 |
| | DS | | 0,6 | 0,9 | 0,7 | 1,8 | |
| | HP-LP | | 0,5 | 1,1 | 1,0 | 1,6 | |
| | LP-R | | | | | 1,2 | |
| UTO | LP-HP | 0,6 | 0,6 | 0,7 | 0,5 | 1,3 | |
| | SS | | 0,7 | 0,8 | 1,1 | 1,3 | 0,5 |
| | DS | | 0,9 | 1,2 | 0,8 | 1,6 | |
| | HP-LP | | 0,7 | 1,2 | 1,4 | 1,6 | |
| | LP-R | | | | | 1,1 | |
| LTO | LP-HP | 2,6 | 1,6 | 1,5 | 1,7 | 2,1 | |
| | SS | | 5,8 | 4,3 | 4,8 | 5,2 | 0,8 |
| | DS | | 4,0 | 3,5 | 3,6 | 3,9 | |
| | HP-LP | | 7,5 | 5,9 | 6,7 | 5,9 | |
| | LP-R | | | | | 1,7 | |
| RA | LP-HP | 2,9 | 2,5 | 2,8 | 2,6 | 2,6 | |
| | SS | | 2,8 | 3,0 | 3,6 | 3,4 | 3,6 |
| | DS | | 1,9 | 1,6 | 1,6 | 1,5 | |
| | HP-LP | | 2,4 | 2,3 | 2,4 | 2,1 | |
| | LP-R | | | | | 3,0 | |
| LA | LP-HP | 3,2 | 3,1 | 2,8 | 2,6 | 4,0 | |
| | SS | | 2,9 | 2,5 | 2,5 | 2,4 | 3,7 |
| | DS | | 2,9 | 2,5 | 2,5 | 3,0 | |
| | HP-LP | | 2,4 | 2,2 | 2,2 | 2,3 | |
| | LP-R | | | | | 4,1 | |
| RL | LP-HP | 15,7 | 8,5 | 6,9 | 6,2 | 1,2 | |
| | SS | | 16,6 | 11,3 | 11,6 | 11,5 | 1,1 |
| | DS | | 4,0 | 2,5 | 2,9 | 2,1 | |
| | HP-LP | | 10,8 | 6,3 | 6,4 | 5,5 | |
| | LP-R | | | | | 1,2 | |
| LL | LP-HP | 3,8 | 7,4 | 6,0 | 6,0 | 3,7 | |
| | SS | | 6,0 | 6,2 | 5,9 | 5,9 | 2,3 |
| | DS | | 7,2 | 6,8 | 7,5 | 6,2 | |
| | HP-LP | | 7,1 | 6,7 | 8,1 | 7,8 | |
| | LP-R | | | | | 3,2 | |

**App 12. The segment's Kinetic energies contribution percentages to hammer head kinetic energy during the LP-HP, SS, DS, HP-LP and Release phases for thrower H, trial 4**

| H4 | | The Turns | | | | | |
|---|---|---|---|---|---|---|---|
| KE of | Phases | Entry | 1 | 2 | 3 | 4 | In Y direction |
| H | LP-HP | 0,1 | 0,3 | 0,4 | 0,6 | 1,5 | |
| | SS | 0,3 | 0,6 | 0,7 | 0,8 | 0,5 | |
| | DS | | 0,6 | 0,8 | 1,0 | 2,0 | |
| | HP-LP | | 0,6 | 0,9 | 1,3 | 1,7 | |
| | LP-R | | | | | 1,4 | |
| UTO | LP-HP | 0,6 | 0,6 | 0,7 | 0,7 | 1,1 | |
| | SS | | 0,7 | 0,9 | 1,1 | 1,0 | 0,4 |
| | DS | | 0,9 | 1,3 | 1,3 | 1,6 | |
| | HP-LP | | 1,0 | 1,3 | 1,7 | 1,7 | |
| | LP-R | | | | | 1,0 | |
| LTO | LP-HP | 2,4 | 2,1 | 1,6 | 2,2 | 2,2 | |
| | SS | | 5,0 | 4,1 | 3,8 | 4,1 | 0,4 |
| | DS | | 3,8 | 3,3 | 3,8 | 4,0 | |
| | HP-LP | | 6,8 | 5,4 | 6,0 | 5,6 | |
| | LP-R | | | | | 1,9 | |
| RA | LP-HP | 2,9 | 2,5 | 2,4 | 2,4 | 2,2 | |
| | SS | | 2,5 | 2,7 | 3,0 | 3,1 | 3,4 |
| | DS | | 1,9 | 1,6 | 1,5 | 1,5 | |
| | HP-LP | | 2,1 | 2,0 | 2,1 | 2,0 | |
| | LP-R | | | | | 2,4 | |
| LA | LP-HP | 3,0 | 2,5 | 2,5 | 2,6 | 2,7 | |
| | SS | | 2,5 | 2,2 | 2,2 | 2,3 | 2,7 |
| | DS | | 2,6 | 2,7 | 2,7 | 2,8 | |
| | HP-LP | | 2,3 | 2,3 | 2,5 | 2,5 | |
| | LP-R | | | | | 2,7 | |
| RL | LP-HP | 17,8 | 8,4 | 6,9 | 7,4 | 0,9 | |
| | SS | | 14,9 | 10,8 | 10,5 | 11,1 | 0,7 |
| | DS | | 3,4 | 2,9 | 2,9 | 1,8 | |
| | HP-LP | | 7,0 | 6,4 | 5,5 | 5,5 | |
| | LP-R | | | | | 0,8 | |
| LL | LP-HP | 4,0 | 5,5 | 5,6 | 5,9 | 3,0 | |
| | SS | | 5,2 | 5,8 | 5,2 | 5,4 | 1,3 |
| | DS | | 6,4 | 6,4 | 7,6 | 5,1 | |
| | HP-LP | | 6,6 | 6,3 | 7,3 | 6,5 | |
| | LP-R | | | | | 2,7 | |

**App 13. The segment's Kinetic energies contribution percentages to hammer head kinetic energy during the LP-HP, SS, DS, HP-LP and Release phases for thrower H, trial 5**

| H5 | | The Turns | | | | | |
|---|---|---|---|---|---|---|---|
| KE of | Phases | Entry | 1 | 2 | 3 | 4 | In Y direction |
| H | LP-HP | 0,2 | 0,4 | 0,5 | 0,5 | 1,1 | |
| | SS | | 0,3 | 0,6 | 0,8 | 0,9 | 0,5 |
| | DS | | 0,6 | 0,8 | 0,8 | 1,5 | |
| | HP-LP | | 0,7 | 0,9 | 1,0 | 1,5 | |
| | LP-R | | | | | 0,9 | |
| UTO | LP-HP | 0,5 | 0,5 | 0,6 | 0,5 | 1,2 | |
| | SS | | 0,5 | 0,7 | 0,9 | 1,0 | 0,4 |
| | DS | | 0,9 | 1,1 | 1,0 | 1,8 | |
| | HP-LP | | 0,7 | 1,1 | 1,3 | 1,7 | |
| | LP-R | | | | | 1,0 | |
| LTO | LP-HP | 2,9 | 2,0 | 1,7 | 2,0 | 2,4 | |
| | SS | | 4,4 | 4,1 | 4,1 | 4,1 | 0,4 |
| | DS | | 3,7 | 3,6 | 4,2 | 4,6 | |
| | HP-LP | | 6,0 | 5,7 | 6,5 | 6,0 | |
| | LP-R | | | | | 1,9 | |
| RA | LP-HP | 2,9 | 2,4 | 2,8 | 2,8 | 2,7 | |
| | SS | | 2,6 | 2,5 | 3,1 | 3,5 | 4,0 |
| | DS | | 1,9 | 1,8 | 1,8 | 1,6 | |
| | HP-LP | | 2,1 | 2,1 | 2,2 | 2,3 | |
| | LP-R | | | | | 3,2 | |
| LA | LP-HP | 2,8 | 2,4 | 2,3 | 2,4 | 3,0 | |
| | SS | | 2,4 | 2,1 | 2,0 | 2,3 | 2,6 |
| | DS | | 2,7 | 2,4 | 2,4 | 2,9 | |
| | HP-LP | | 2,2 | 2,0 | 2,1 | 2,6 | |
| | LP-R | | | | | 2,9 | |
| RL | LP-HP | 16,2 | 9,6 | 8,0 | 6,0 | 1,1 | |
| | SS | | 14,4 | 10,5 | 10,7 | 9,6 | 0,7 |
| | DS | | 4,1 | 3,1 | 2,8 | 2,2 | |
| | HP-LP | | 6,4 | 5,7 | 6,1 | 5,8 | |
| | LP-R | | | | | 0,9 | |
| LL | LP-HP | 4,1 | 5,5 | 5,4 | 6,3 | 2,9 | |
| | SS | | 5,3 | 5,1 | 5,7 | 5,9 | 1,4 |
| | DS | | 6,8 | 6,5 | 7,9 | 5,4 | |
| | HP-LP | | 6,7 | 6,0 | 7,7 | 7,0 | |
| | LP-R | | | | | 2,3 | |

**App 14. The segment's Kinetic energies contribution percentages to hammer head kinetic energy the LP-HP, SS, DS, HP-LP and Release phases for thrower K, trial 2**

| K2 | | The Turns | | | | | |
|---|---|---|---|---|---|---|---|
| KE of | Phases | Entry | 1 | 2 | 3 | 4 | In Y direction |
| H | LP-HP | 0,4 | 0,9 | 1,6 | 2,4 | 4,9 | |
| | SS | | 1,0 | 1,8 | 2,2 | 3,7 | 1,6 |
| | DS | | 1,4 | 2,1 | 3,4 | 6,8 | |
| | HP-LP | | 1,5 | 2,5 | 3,7 | 6,6 | |
| | LP-R | | | | | 3,4 | |
| UTO | LP-HP | 0,6 | 0,6 | 1,1 | 0,8 | 1,3 | |
| | SS | | 0,9 | 1,1 | 1,4 | 1,3 | 0,5 |
| | DS | | 1,1 | 1,3 | 1,4 | 1,9 | |
| | HP-LP | | 1,3 | 1,5 | 1,9 | 2,0 | |
| | LP-R | | | | | 1,0 | |
| LTO | LP-HP | 1,3 | 1,4 | 1,9 | 1,5 | 1,3 | |
| | SS | | 3,6 | 3,1 | 2,7 | 2,3 | 0,1 |
| | DS | | 2,9 | 2,3 | 2,6 | 2,3 | |
| | HP-LP | | 5,3 | 3,7 | 3,4 | 2,8 | |
| | LP-R | | | | | 0,8 | |
| RA | LP-HP | 2,5 | 2,3 | 2,0 | 2,0 | 1,8 | |
| | SS | | 2,8 | 2,5 | 2,4 | 2,6 | 2,2 |
| | DS | | 1,7 | 1,2 | 1,4 | 1,3 | |
| | HP-LP | | 2,3 | 1,6 | 1,8 | 1,8 | |
| | LP-R | | | | | 2,0 | |
| LA | LP-HP | 2,0 | 1,9 | 1,5 | 1,5 | 2,1 | |
| | SS | | 1,8 | 1,5 | 1,3 | 1,4 | 1,7 |
| | DS | | 2,2 | 1,8 | 1,6 | 2,1 | |
| | HP-LP | | 1,7 | 1,6 | 1,5 | 1,9 | |
| | LP-R | | | | | 2,0 | |
| RL | LP-HP | 9,6 | 7,2 | 6,0 | 5,0 | 0,4 | |
| | SS | | 9,8 | 7,9 | 6,8 | 7,4 | 0,3 |
| | DS | | 2,6 | 1,8 | 1,7 | 0,8 | |
| | HP-LP | | 6,5 | 2,2 | 2,6 | 2,5 | |
| | LP-R | | | | | 0,3 | |
| LL | LP-HP | 3,7 | 5,2 | 4,3 | 4,9 | 2,1 | |
| | SS | | 4,9 | 4,7 | 3,9 | 4,4 | 0,6 |
| | DS | | 6,7 | 6,0 | 6,1 | 4,6 | |
| | HP-LP | | 6,2 | 5,9 | 5,6 | 6,1 | |
| | LP-R | | | | | 1,3 | |

**App 15. The segment's Kinetic energies contribution percentages to hammer head kinetic energy during the LP-HP, SS, DS, HP-LP and Release phases for thrower K, trial 3**

| K3 | | The Turns | | | | | |
|---|---|---|---|---|---|---|---|
| KE of | Phases | Entry | 1 | 2 | 3 | 4 | In Y direction |
| H | LP-HP | 0,7 | 1,0 | 1,6 | 2,6 | 3,9 | |
| | SS | | 1,2 | 1,7 | 2,4 | 3,4 | 1,4 |
| | DS | | 1,4 | 2,1 | 3,5 | 5,5 | |
| | HP-LP | | 1,7 | 2,3 | 3,5 | 5,3 | |
| | LP-R | | | | | 3,3 | |
| UTO | LP-HP | 0,5 | 0,7 | 1,1 | 0,9 | 1,1 | |
| | SS | | 0,8 | 1,0 | 1,2 | 1,1 | 0,3 |
| | DS | | 1,0 | 1,4 | 1,2 | 1,7 | |
| | HP-LP | | 1,1 | 1,3 | 1,4 | 1,6 | |
| | LP-R | | | | | 0,9 | |
| LTO | LP-HP | 2,1 | 1,6 | 1,8 | 1,5 | 1,5 | |
| | SS | | 3,9 | 2,9 | 2,3 | 1,8 | 0,7 |
| | DS | | 2,3 | 2,5 | 2,0 | 2,1 | |
| | HP-LP | | 4,4 | 3,5 | 2,7 | 2,3 | |
| | LP-R | | | | | 1,3 | |
| RA | LP-HP | 2,8 | 2,4 | 2,2 | 2,2 | 1,8 | |
| | SS | | 2,6 | 2,6 | 2,5 | 2,8 | 2,4 |
| | DS | | 1,7 | 1,5 | 1,5 | 1,4 | |
| | HP-LP | | 1,9 | 1,9 | 1,9 | 2,2 | |
| | LP-R | | | | | 1,9 | |
| LA | LP-HP | 1,6 | 1,7 | 1,6 | 1,7 | 2,2 | |
| | SS | | 1,7 | 1,4 | 1,4 | 1,4 | 1,8 |
| | DS | | 1,9 | 1,7 | 1,7 | 2,1 | |
| | HP-LP | | 1,8 | 1,5 | 1,5 | 1,7 | |
| | LP-R | | | | | 2,1 | |
| RL | LP-HP | 13,7 | 6,3 | 4,9 | 4,8 | 0,4 | |
| | SS | | 9,8 | 6,3 | 6,9 | 6,9 | 0,3 |
| | DS | | 2,1 | 1,6 | 1,6 | 1,0 | |
| | HP-LP | | 2,5 | 2,9 | 3,9 | 3,6 | |
| | LP-R | | | | | 0,4 | |
| LL | LP-HP | 4,2 | 4,3 | 4,1 | 3,5 | 2,2 | |
| | SS | | 5,9 | 4,9 | 4,2 | 3,6 | 1,3 |
| | DS | | 5,5 | 5,4 | 4,9 | 3,8 | |
| | HP-LP | | 6,4 | 5,8 | 5,3 | 4,9 | |
| | LP-R | | | | | 1,9 | |

**App 16. The segment's Kinetic energies contribution percentages to hammer head kinetic energy during the LP-HP, SS, DS, HP-LP and Release phases for thrower K, trial 6**

| K6 | | The Turns | | | | | |
|---|---|---|---|---|---|---|---|
| **KE of** | **Phases** | Entry | 1 | 2 | 3 | 4 | In Y direction |
| H | LP-HP | 0,6 | 0,9 | 1,6 | 2,4 | 4,6 | |
| | SS | | 1,2 | 1,9 | 2,3 | 3,7 | 2,1 |
| | DS | | 1,2 | 2,2 | 3,3 | 6,3 | |
| | HP-LP | | 1,6 | 2,7 | 3,6 | 6,3 | |
| | LP-R | | | | | 3,7 | |
| UTO | LP-HP | 0,5 | 0,8 | 1,1 | 1,2 | 1,3 | |
| | SS | | 0,9 | 1,4 | 1,6 | 1,3 | 0,4 |
| | DS | | 1,2 | 1,5 | 1,6 | 1,8 | |
| | HP-LP | | 1,3 | 2,0 | 2,0 | 2,0 | |
| | LP-R | | | | | 1,0 | |
| LTO | LP-HP | 2,2 | 1,9 | 2,0 | 2,3 | 1,8 | |
| | SS | | 4,1 | 3,8 | 3,6 | 2,7 | 0,4 |
| | DS | | 2,8 | 2,6 | 3,0 | 2,7 | |
| | HP-LP | | 5,1 | 4,8 | 4,0 | 3,1 | |
| | LP-R | | | | | 1,3 | |
| RA | LP-HP | 3,0 | 2,4 | 2,3 | 2,2 | 1,7 | |
| | SS | | 2,8 | 2,5 | 2,5 | 2,7 | 2,2 |
| | DS | | 1,8 | 1,5 | 1,4 | 1,3 | |
| | HP-LP | | 2,2 | 1,8 | 1,7 | 1,9 | |
| | LP-R | | | | | 1,9 | |
| LA | LP-HP | 1,7 | 1,8 | 1,7 | 1,6 | 2,4 | |
| | SS | | 1,7 | 1,5 | 1,4 | 1,4 | 2,1 |
| | DS | | 2,1 | 2,1 | 2,0 | 2,2 | |
| | HP-LP | | 1,8 | 1,9 | 1,8 | 1,9 | |
| | LP-R | | | | | 2,3 | |
| RL | LP-HP | 12,6 | 6,8 | 6,1 | 5,6 | 0,5 | |
| | SS | | 10,1 | 7,2 | 8,2 | 8,3 | 0,3 |
| | DS | | 2,3 | 1,9 | 1,6 | 0,9 | |
| | HP-LP | | 5,3 | 2,4 | 3,9 | 3,7 | |
| | LP-R | | | | | 0,4 | |
| LL | LP-HP | 2,1 | 1,6 | 1,3 | 1,5 | 1,0 | |
| | SS | | 2,2 | 1,7 | 1,2 | 1,4 | 0,4 |
| | DS | | 1,8 | 1,6 | 1,6 | 1,5 | |
| | HP-LP | | 2,2 | 1,9 | 1,4 | 1,4 | |
| | LP-R | | | | | 0,8 | |

App 17. The body kinetic Energy contribution percentages to hammer head kinetic energy during the LP-HP, SS, DS, HP-LP and Release phases for both throwers H and K in all trials

| | | Phases | | | | |
|---|---|---|---|---|---|---|
| **Trials** | **Turns** | **LP-HP** | **SS** | **HP-LP** | **DS** | **LP4-R** |
| **H1** | Entry | 31,9 | | | | |
| | 1 | 19,7 | 32,5 | 25,1 | 19,2 | |
| | 2 | 18,6 | 25,4 | 23,7 | 17,4 | |
| | 3 | 19,2 | 22,1 | 21,4 | 18 | |
| | 4 | 12,8 | 21,8 | 21,5 | 17,9 | 13,8 |
| | Y direction | | 9 | | | |
| **H3** | Entry | 29 | | | | |
| | 1 | 24 | 35,1 | 31,6 | 21,4 | |
| | 2 | 21 | 28,8 | 25,7 | 19,1 | |
| | 3 | 20 | 30,4 | 28,2 | 19,6 | |
| | 4 | 16,4 | 30,7 | 26,9 | 20 | 15,4 |
| | Y direction | | 12,6 | | | |
| **H4** | Entry | 30,9 | | | | |
| | 1 | 21,9 | 31,1 | 26,4 | 19,6 | |
| | 2 | 20,1 | 27 | 24,5 | 18,9 | |
| | 3 | 21,7 | 26,5 | 26,3 | 20,8 | |
| | 4 | 13,6 | 27,9 | 25,7 | 18,8 | 12,8 |
| | Y direction | | 9,3 | | | |
| **H5** | Entry | 29,6 | | | | |
| | 1 | 22,9 | 30 | 24,7 | 20,8 | |
| | 2 | 21,3 | 25,6 | 23,6 | 19,5 | |
| | 3 | 20,6 | 27,3 | 27,1 | 20,8 | |
| | 4 | 14,5 | 27,2 | 27 | 20 | 13,1 |
| | Y direction | | 10,1 | | | |
| **K2** | Entry | 20,1 | | | | |
| | 1 | 19,6 | 24,7 | 24,8 | 18,6 | |
| | 2 | 18,4 | 22,6 | 19 | 16,5 | |
| | 3 | 18,1 | 20,7 | 20,5 | 18,4 | |
| | 4 | 13,9 | 23 | 23,7 | 19,9 | 10,7 |
| | Y direction | | 7 | | | |
| **K3** | Entry | 25,6 | | | | |
| | 1 | 17,9 | 25,9 | 19,8 | 15,9 | |
| | 2 | 17,2 | 20,7 | 19,2 | 16,2 | |
| | 3 | 17,3 | 20,9 | 20,1 | 16,6 | |
| | 4 | 13 | 21,2 | 21,6 | 17,5 | 11,8 |
| | Y direction | | 8,3 | | | |
| **K6** | Entry | 22,8 | | | | |
| | 1 | 16,2 | 23 | 19,5 | 13,1 | |
| | 2 | 16 | 19,9 | 17,5 | 13,4 | |
| | 3 | 16,8 | 20,8 | 18,5 | 14,6 | |
| | 4 | 13,2 | 21,4 | 20,2 | 16,8 | 11,4 |
| | Y direction | | 7,9 | | | |