Universidade de Trás-os-Montes e Alto Douro

The importance of IMU devices as a kinematic analysis complement in javelin throw

- Versão Final -

Master Thesis

International Master in Performance Analysis of Sports

Candidate: Flávia Rodrigues da Costa

Supervisor: Professora Dra. Eduarda Maria Coelho

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Vila Real, 2020

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Declaração

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Declaro que a presente dissertação é fruto de um trabalho efetuado por mim e pelos meus orientadores. O conteúdo inerente é de cariz original sendo todas as fontes devidamente consultadas e citadas tanto no correr de texto bem como na bibliografia final. Por fim, declaro que o mesmo trabalho não foi apresentado em nenhuma outra instituição para obtenção de grau académico.

In all science, error precedes the truth, and it is better it should go first than last.

Horace Walpole

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TABLE OF CONTENTS

List of Figures

List of Tables

List of Abbreviations and symbols

IAAF	International Association of Athletics Federation
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
IMU	Inertial Measurement Unit
2D	Two-dimensional
3D	Three-dimensional
DLT	Direct Linear Transformation
nm	non-mentioned
m	male
f	female
V	Velocity
T	Time
H	Height
V_0	Release velocity
H_0	Release height
$\angle_0$	Release angle
Dist	Distance
Sup	Superior
DS	Double support
CM	Center of mass
VIDx_hip	video hip's maximum antero-posterior velocity
VIDy_hip	video hip's maximum proximo-distal velocity
VIDz_hip	video hip's maximum medio-lateral velocity
VIDv_hip	Video hip's resultant velocity
IMUx_hip	IMU hip's maximum antero-posterior acceleration
IMUy_hip	IMU hip's maximum proximo-distal acceleration
IMUz_hip	IMU hip's maximum medio-lateral acceleration
IMUa_hip	IMU hip's resultant acceleration
VIDx_jav	video javelin's maximum antero-posterior velocity

VIDy_jav	video javelin's maximum proximo-distal velocity
VIDz_jav	video javelin's maximum medio-lateral velocity
VIDv_jav	Video javelin's resultant velocity
IMUx_jav	IMU javelin's maximum antero-posterior acceleration
IMUy_jav	IMU javelin's maximum proximo-distal acceleration
IMUz_jav	IMU javelin's maximum medio-lateral acceleration
IMUa_jav	IMU javelin's resultant acceleration
r	Pearson's correlation or Spearman's correlation coefficient
p	p-value, statistical significance
M	Mean
SD	Standard deviation

Background

The javelin throw is one of the four athletics throwing events and it's recognized by its technique complexity (Hassan, 2015). As any other athletic throw, the main purpose of javelin throwing is to enable the implement to land as far as possible from the foul line (Bartonietz, 2000). The discipline movement characteristics indicate an acyclic translator motion (Frane, Borović, & Foretić, 2011) demanding a great ballistic capacity by enhancing predominately the explosive muscular ability of the thrower (Hassan, 2015). The javelin throw can be deconstructed in distinctive phases: the approach, transition, block and release, and follow-through. The first phase is the run-up which anticipates the javelin's withdrawal. At this point, the thrower starts to develop and storing all the body velocity and kinetic energy which is transferred to the throw itself. The transition or crossover phase prepares the thrower for an optimal upper body control and it's characterized by an active action of hip and legs. The penultimate step, meaning the impulse stride, at its final instant, it's a vigorous forward drive of the final left leg (delivery) followed by the block and respective release. The block and release are the energic culminate of the preceding phases (Brown, Webb, & Sing, 2000). Regardless the thrower's body and implement weight, the human body velocity is an extremely crucial factor at the beginning of the delivery, shaping the kinetic energy accumulated on the previous phases (Bartonietz, 2000). Therefore, the final throw phases imply a great physical and physiological load on the thrower's body, especially at the block instant (Frane et al., 2011). Accordingly, the javelin throw is considered one of the most complex athletics events (Silvester, 2003). Throughout time, investigators have tried to understand this sport and its technique aiming the improvement of performance (distance). Traditionally, the release parameters have been recorded with high-speed filming/video-shooting (Viitasalo et al., 2003), using a two-dimensional or three-dimensional analyses of the collected information (Best, Bartlett, & Morriss, 1993; Campos, Brizuela, & Ramón, 2004; Campos, Brizuela, Ramón, & Gámez, 2002; Campos, Navarro, Vera, & Llobregat, 1994; Hussain & Bari, 2012; Jung, Kim, Kang, Chae, Lim, Yoon & Lee, 2012; Kaur & Deol, 2016; Leigh et al., 2013; Liu, Leigh, & Yu, 2010, 2014; Mero, Komi, Korjus, Navarro, & Gregor, 1994; Morriss, Bartlett, & Fowler, 1997; Saratlija, Zagorac, & Babić, 2013; Panoutsakopoulos &

Kollias, 2013) Nevertheless, these methods are considered slow ways to provide feedback for coaches and athletes (Viitasalo et al., 2003). According to Hubbard and Alaways (1989) in a training environment, information must be understandable and accessible within a relatively short period of time, so that the following throws' technique can be upgraded based on the information taken from the previous one. That's why recently, wearable technologies for monitoring human movement have become undoubtedly popular (Knight et al., 2007). Athletes are starting to set a growing role on the use of wearable sensor technology, since it enhances immediate feedback on workloads and technique (Li et al., 2016). Developments on these equipment have allowed individual athletes, team sports, physicians to monitor the motion associated (Loader et al., 2012), workload (Mooney et al., 2011; Varley et al., 2012) and biomarkers (Foster et al., 2010) in attempts to enhance performance and avoid injury. Lately, the Inertial Measurement Unit (IMU) based sensors have emerged to quantify human movement. IMU used in a biomechanical context are either build on accelerometers alone, a grouping with gyroscopes or a combination with both gyroscopes and magnetometers (Wirth et al., 2019). The IMU sensors have been validated for biomechanical analysis in areas like gait analysis (Kavanagh & Menz, 2008), swimming biomechanics (Magalhaes, Vannozzi, Gatta, & Fantozzi, 2015) and running kinematics (Provot, Chiementin, Oudin, Bolaers, & Murer, 2017). However, there are no studies on javelin throw using IMU devices. The present dissertation aims to review the studies related with javelin throw's kinematic analysis in order to recognize what has been investigated and what's lacking to improve performance assessment. Finally, after overviewing the past of javelin's throw analysis, a new technology was applied to evaluate javelin's throw kinematic parameters, aiming the future utilization on training and competition contexts.

Chapter 1

The kinematic analysis applied to javelin throw: a systematic review

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The kinematic analysis applied to javelin throw: a systematic review

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Abstract

Introduction: The javelin throwing is a peculiar discipline in which the thrower intents to transfer the greatest acceleration from the run-up to the javelin at the instant of release. Javelin throw and biomechanics have kept a strong relationship, assisting on understanding its technique and its connection with performance outcomes. The present review aims to complete a deep overview of the studies related to javelin throw's kinematic analysis, understand how javelin's technical information has been assessed, and highlight future perspectives on kinematic tools for javelin's evaluation. **Methods:** The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) principles were followed in this review. PubMEd/MEDLINE, World Wide Science and IAAF's research database. **Results:** Distance: Elite male=: 81.22 ± 4.01 m; Elite female= 60.98 ± 2.35 m; Non-elite male: 50.84 ± 13.6 m; Non-elite female: 34.83 m. Release Velocity: Elite male= 28.24 ± 0.87 m/s; Elite female= 23.53 ± 1.27 m/s; Non-elite male= 18.58 ± 4.33 m/s; Non-elite female= 17.42 m/s. Release Height: Elite male= 1.94 ± 0.08 m; Elite female= 1.82 ± 0.06 m; Non-elite male= 1.99 ± 0.13 m; Non-elite female= 1.89 m. Release Angle: Elite male: 34.38 ± 2.22º; Elite female: 35.52 ± 3.28 º; Non-elite male: 36.4º; Non-elite female: 44.2º. **Conclusions:** The release velocity is considered the most important parameter determining the distance thrown. The studies on javelin throwing use the video recording to analyze its kinematic parameters. Several parameters do not describe a linear efficiency tendency and show that different throwing techniques end out to be similarly effective.

Key-words: javelin throw, javelin throw kinematic analysis, javelin throw biomechanics

1.1. Introduction

Some athletic throwing events, namely javelin throw, are characterized as acyclic translator movements (Frane et al., 2011). In a kinesiological view, throws are defined as ballistic movements, characterized by a great agonists activation which is followed by its relaxation and finishes with a de-acceleration of the agonists related with the antagonists' action or passive extension of the connective tissues (Harasin, 2002). Specifically, the javelin throw stands out from the other throws by its overarm throwing feature, and accordingly, it is mandatory to throw over the shoulder or upper part of the throwing arm (Bartonietz, 2000; Van den Tillaar, 2005).

The javelin's competition take place in particular standardized conditions (e.g. weight of implements, run-up characteristics) defined by the International Association of Athletics Federations (IAAF) (Harasin, 2002). During the competitions, the participants are ranked according to the distance accurately measured in meters (Harasin, 2002). Hence, the outcomes are objective and devoid of any kind of judge evaluation (Harasin, 2002). The implement weight is relatively small comparing with the other throws (600 gr for women and 800 gr for men) (Frane et al., 2011). Several authors have separated the javelin into distinct phases and different nomenclatures are utilized. Commonly, the throw is divided into: the approach phase (cyclic and acyclic phases), followed by the delivery phase (impulse phase, delivery phase and release phase) and finally, the follow through (recovery) (Bennet et al., 2017a; Jung et al., 2012; Menzel, 1986; Morriss & Bartlett, 1996).

The javelin throwing is a peculiar discipline in which the thrower intents to transfer the greatest acceleration from the run-up to the javelin at the moment of release (Silvester, 2003). The final throw phase represents a great physical and physiological challenge, especially when the thrower suddenly stops running and blocks (Frane et al., 2011). Accordingly, the javelin throw is one of the most complexes athletics events (Silvester, 2003). Given its complexity, investigators have studied this event, trying to understand its technique to improve the distance thrown (Viitasalo et al., 2003). The outcome distance depends on the values of the release parameters and the flight aerodynamics (Viitasalo et al., 2003).

Javelin throw and biomechanics have kept a strong relationship, since the biomechanics assist on understanding its technique and its connection with performance indicators (Viitasalo et al., 2003). Several studies evaluated parameters such as pull distance and steps length/duration (Jung et al., 2012; Mero et al., 1994); also release angle, attack angle, and body segments angles (e.g. tilt, rotation, abduction and extension) (Jung et al., 2012; Liu et al., 2010, 2014; Saratlija et al., 2013; Panoutsakopoulos & Kollias, 2013) release velocity (horizontal, vertical and/or lateral) (Mero et al., 1994; Viitasalo et al., 2003) and release height (Jung et al., 2012; Panoutsakopoulos & Kollias, 2013); angular velocity (Liu et al., 2014) and velocity of the segments (e.g. elbow, shoulder and hip) (Campos et al., 2004, 2002). The majority of previous studies carried out their analysis through video analysing software, using a two-dimensional or three-dimensional kinematic analysis (Best, Bartlett, & Morriss, 1993; Campos, Brizuela, & Ramón, 2004; Campos, Brizuela, Ramón, & Gámez, 2002; Campos, Navarro, Vera, & Llobregat, 1994; Hussain & Bari, 2012; Jung et al., 2012; Kaur & Deol, 2016; Leigh et al., 2013; Liu et al., 2010, 2014; Mero et al., 1994; Morriss, Bartlett, & Fowler, 1997; Saratlija et al., 2013; Panoutsakopoulos & Kollias, 2013). A different method was used by Viitasalo, Mononen and Norvapalo (2003) reporting a research based on an Infrared Photocell Gate to measure the release parameters on the foul line. Hence, the literature available is mainly video analysis based. According to Bartlett and Best (1988), the three-dimensional analysis is recommended to improve technique's feedback. Traditionally, the release parameters have been recorded using high-speed filming/video-shooting. However, this method turns out to be a slow way to provide feedback for coaches and athletes (Viitasalo et al., 2003). As alleged by Hubbard and Alaways (1989) in a training context, information must be accessible within a relatively short period of time, so that the following throws' technique can be upgraded based on the information taken from the previous one. That's why in the past few years, wearable technologies for monitoring human movement have become undoubtedly popular (Knight et al., 2007). A trend has started to rise around athletics environment to monitor performance during real-time activities (Li et al., 2016). Devices, such as accelerometers, turn out to be an attractive instrument for detection and measurement of human motion (Knight et al., 2007).

The aim of the present review is to complete a deep overview of the studies related with javelin throw's kinematic analysis in order to recognize what's been investigated and what's lacking to improve performance assessment. Are there studies that use new technologies? Are these new technologies helpful to improve feedback's celerity and maintain/improve its quality? Thus, this review intents to understand the past to identify the emergent necessities and trends of new technology.

1.2. Methodology

1.2.1. Protocol and Registration

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) principles were followed in this review. The PRISMA philosophy includes 27-item checklist and a four-phase flow diagram which aims to help authors reporting systematic reviews and meta-analysis (Moher, Liberati, Tetzlaff, Altman, & The PRISMA group, 2010).

1.2.2. Selection Criteria

Studies investigating javelin throw were included if they met the following criteria: (1) kinematical analysis of javelin; (2) analysis of javelin's parameters mainly at the last phases; (3) body segments contributions and its connection with the outcome; (4) relationship between the kinematic parameters and the performance; (5) written in English or Portuguese; (6) published in a peer-published journal or official reports from the International Association of Athletics Federations (IAAF).

Studies were excluded if they met one or more of the following reasons: (1) not written in English; (2) not published in a peer journal or non-official reports from the International Association of Athletics Federations (IAAF); (3) not about javelin throw's analyses itself.

1.2.3. Literature Search

A systematic and computerized search of PubMEd/MEDLINE and World Wide Science was conducted using the key-words “javelin throw”, “javelin throw analysis”, “javelin throw kinematics” and “javelin throw biomechanics”. Also, in the International Association of Athletics Federations’s (IAAF) Research Database website are available official biomechanical reports of the latest World Championships which are additional relevant data on javelin throw. After literature search completion, a screening was performed to retrieve relevant publications.

1.2.4. Quality Assessment

All pertinent studies were submitted into a formal methodological assessment by two independent reviewers. There’s no validated quality assessment protocol appropriated for this study area (i.e. sports performance) (Costa, Balasekaran, Vilas-Boas, & Barbosa, 2015), therefore the methodological quality of each paper was evaluated by Downs and Black (1998) quality index which is divided on the following categories: Reporting (10 items), External validity (3 items), Internal validity - Bias (7 items), Internal validity - Confounding (6 items) and Power (1 item). Subsequently, the index is composed by 27 items where each answer is scored 0 or 1, except for one item in the Reporting subscale which scored 0 to 2 and the single item on the Power scored 0 to 5. The total maximum score is 32 (Downs & Black, 1998). However, in order to adapt the index to this study field, some adjustments were implemented and the following items weren´t considered: (i) item 5, item 14, item 15, item 17, item 21, item 22, item 23, item 24, item 25 (Macadam, Cronin, & Feser, 2019; Moens et al., 2019) and item 27 (Feitosa, Correia, Barbosa, & Castro, 2019; Macadam et al., 2019) were not contemplated; (ii) the words ‘patient’ was replaced by ‘participant’ and ‘treatment’ by ‘testing’ (Feitosa et al., 2019). This modified version attributes a score value of 0 or 1 on the index reduced subcategories: Reporting (9 items), External validity (3 items), Internal validity - (5 items). A total score <10/17 was considered as low quality and scores ≥10/17 were assumed to be high quality (Macadam et al., 2019; Moens et al., 2019) and studies with higher total scores were assumed to have a greater value (Feitosa et al., 2019). When required, disagreements between reviewers were solved by dialogue and consensus.

1.2.5. Data Extraction

The data collection was independently performed by one author in its master thesis context. The point of this search was to collect what has been studied around the javelin throw, which technologies have been used to access performance and what's emerging around the human movement analysis which can be applied on the javelin throw.

1.3. Results

1.3.1. Study Selection

The literature search throughout database identified 45 studies. Full-text analysis of 33 studies was performed, with 26 studies meeting inclusion criteria defined previously on this systematic review (Figure 1).

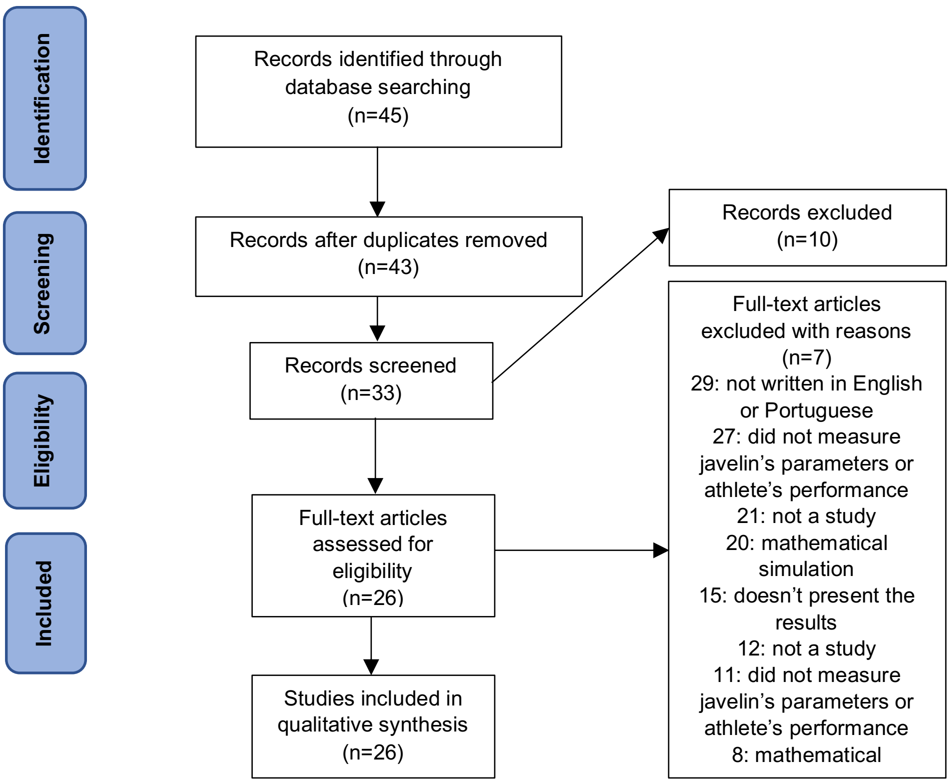

Figure 1 *– PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) flowchart. Javelin Throw analysis, n=26*

Table 1 *- Description of the included studies and methodological quality score, n=26*

	Sample, n	**Context**	**Age, yrs (M±SD)**	**Gender, f/m**	**Aim**	**Quality score**
(Aleksić-Veljković et al., 2012)	10 Serbian and 3 elite javelin throwers	Javelin throwers of the 2011 Serbian Cup Final (Novi Sad) and javelin throwers of the 2011 World Championships (Daegu)	18.3; 27.6	f	Determine differences in kinematic parameters between the elite competitors in the World Championship 2011 and Serbian Cup competitors in 2011.	**13**
(Bartlett et al., 1996)	6 novices and 6 over 50m	Novice and club throwers groups carried out on a Tartan javelin runway at the University of Innsbruck, Austria, in 1992. Elite group from the 1993 AAA National Championships (England)	nm	m	Determine differences between values of 3D release parameters for male javelin throwers of different skills levels and relate these features with javelin throw technique.	**12**
(Bennett, Walker, Bissas, & Merlino, 2017a)	13 javelin throwers	2017 IAAF World Championships, London	nm	m	Analyze biomechanically the Men's final in London's World Championship 2017	**9**
(Bennett, Walker, Bissas, & Merlino, 2017b)	12 javelin throwers	2017 IAAF World Championships, London	nm	f	Analyze biomechanically the Women's final in London's World Championship 2017.	**9**
(Best et al., 1993)	5 male 4 female	1991 World Student Games, Sheffield.	nm	m & f	Obtain accurate 3D release parameters values for elite javelin throwers in a top-level competition; relate these features with javelin throw technique; compare 2D with 3D data.	**9**
(Campos et al., 2004)	7	1999 World Athletics Championships, Sevilla	nm	m	Compare throwers individual models in the light of the documented data available on the biomechanical analysis of javelin throw.	**11**
(Campos et al., 2002)	8 spanish and 7 elite	Spanish National Athletic Championship in	nm	m	Compare the differences between Spanish javelin	**11**

		Valencia 2001 and World Athletic Championships in Sevilla 1999			throwers and a group of world class javelin throwers.	
(Campos et al., 1994)	2	Currently, the best Spanish javelin throwers	nm	m	Find out significant relations between given parameters; understand the influence that each of them has in performance.	**9**
(Hassan, 2015)	20	Sport Students selected randomly	18 ± 0.7	m	Identify the use of biomechanical simulation system to evaluate physical variables in javelin throw.	**12**
(Hussain & Bari, 2012)	6	Javelin throwers from Aligarh Muslim University in All-India Athletic meets from 2008 to 2010.	21.87 ± 1.64	m	Investigate the relationship between the result and the kinematic parameters of javelin throw to clarify the individuality of the movement.	**12**
(Ito, Ishikawa, Isolehto, Komi & Murakami, Tanabe, 2006)	8 elite and 49 Japanese javelin throwers	2005 IAAF World Championships, Helsinki and the Japanese throwers participated in four domestic athletic meetings	nm	m	Clarify the characteristics of the throwing movement in the javelin by investigating the relationships between kinematic parameters of the movement and the distance thrown.	**12**
(Jung et al., 2012)	8	2011 IAAF World Championships, Daegu	nm	f	Provide data on the throwing skills of world class athletes and analyse the kinematic variables for the women's javelin.	**12**
(Kaur & Deol, 2016)	5	India inter university level from Punjabi University	18-25	m	Investigate the relationship between the result and the kinematic parameters of javelin throw to clarify the individuality of the movement.	**11**
(Komi & Mero, 1985)	5 male 6 female javelin throwers	1984 Olympic Games, Los Angeles	nm	m & f	Examine the biomechanical features of male and female in Los Angeles Olympic Games to offer coaches' more information.	**12**
(Kunz & Kaufmann, 1983)	12 decathletes and 2 javelin throwers	National Swiss Decathlon Competition in 1978, Weinfelden	19-27	m	Correlate biomechanical factors and maximal distance thrown.	**11**

(Lehmann, 2010)	12 male 13 female javelin throwers	2009 IAAF World Championships, Berlin	nm	m & f	Give a guidance for coaches and athletes to prepare for future high-level competitions. Parameters describing the throwing technique were averaged for the two groups of finalists and compared to find those that explained the differences in the final displacements.	**10**
(Leigh et al., 2013)	40 female 40 male	USATF Championships from 2007 to 2010	nm	m & f	Calculate the upper extremity kinetics of elite javelin throwers to determine associations between javelin technique variables and upper extremity kinetic variables.	**13**
(Liu et al., 2010)	30 male 30 female	Elite javelin throwers who competed in the 2007 and 2008 USA Track and Field Outdoor National Championships	nm	m & f	Analyze the sequences of lower and upper extremity segments and joints angular motions in javelin throw.	**12**
(Liu et al., 2014)	32 male 30 female	Elite javelin throwers who competed in the 2007 and 2008 USA Track and Field Outdoor National Championships	nm	m & f	Determine the effects of sequence initiations of trunk and arms angular motions and the sequence of maximum trunk and arm angular velocities in javelin's throw.	**13**
(Mero et al., 1994)	11 male 11 female	1992 Olympic Games, Barcelona	26 ± 3.2; 27.1 ± 4.7	m & f	Investigate body segment contributions in male and female javelin throwers.	**13**
(Morriss, Bartlett, & Fowler, 1997)	12 elite javelin throwers	1995 IAAF World Championships, Gothenburg	nm	m	Accurately record the biomechanical parameters and provide a better understanding how release speeds are achieved.	**10**
(Panoutsakopoulos & Kollias, 2013)	16	IAAF competitions held in Greece between 2006 and 2009	28.5 ± 4.3	f	Quantify the spatio-temporal and kinematical parameters of the delivery phase and release parameters of the javelin throw executed by top female athletes in competition.	**13**

(Panoutsakopoulos, Vujkov, Kotzamanidou, & Vujkov, 2016)	7	Young Club level Serbian javelin throwers	19 ± 1.0	m	Investigate the correlation of the parameters with the throwing distance of young javelin throwers.	**12**
(Saratlija et al., 2013)	16	European Junior Championships 2009, Novi Sad	17-19	m	Define the influence of the kinematic parameters in the javelin throw outcomes.	**13**
(Viitasalo et al., 2003)	26 male 15 female	Javelin throwers competing in 10 international competitions between 1995 and 1998 in Finland	nm	m & f	Investigate the effects of the release speed, release angle and uncorrected angle of attack determined at the foul line.	**13**
(Whiting, Gregor, & Halushka, 1991)	8 javelin throwers	Javelin throwers involved on U.S Olympic Committee's Elite Athlete Project, competing at five meets during 1987-1988	27.8 ± 2.6	m	Provide important information on body segments and release characteristics of new-rules performance in experienced male throwers.	**10**

* nm – non-mentioned; m – male; f – female.

Table 2 – *Methods, main results and relevant conclusions of the included studies, n=26*

	Method	**Main results**	**Conclusions**
(Aleksić-Veljković et al., 2012)	Serbian Cup: 1 CASIO FX high speed camera (300 fps) placed laterally to the runway filming the impulse stride, delivery stride and release. 2D kinematic analysis with HUMAN software.	(M ± SD): Result= 34.83 ± 6.72 m, V_0= 17.42 ± 3.74 m/s, H_0= 1.89 ± 0.09 m, $\angle_{attitude}$= 43.7 ± 6.11 °, $\angle_0$= 44.2 ± 5.67 °, $\angle_{attack}$= 0.9 ± 0.88 °, $T_{impulse\ stride}$= 347.4 ± 42.40 ms, $T_{delivery\ stride}$= 180.1 ± 37.71 ms, $T_{release}$= 153 ± 25.9 ms, $Dist._{impulse\ stride}$= 1.55 ± 0.33 m, $Dist._{delivery\ stride}$= 1.19 ± 0.21 m	In order to ensure a proper training load, it's necessary to understand the biomechanical and neuro-muscular demands of this athletic discipline. The results and information about movement parameters should be used more often by the coaches.
(Bartlett et al., 1996)	Novice and standard athletes: 2 PANASONIC F15 Video Cameras (50 fps). Video recording digitized using Peak Performance System (3D analysis). Elite athletes: 2 PHOTOSONICS 1PL high-speed Video Cameras (100 Hz)	(M ± SD) Elite: Result= 74.7 ± 1.77 m; V_0= 27 ± 0.9 m/s; $\angle_0$= 37.1 ± 2.56º; $\angle_{attack}$=0.34 ± 4.31º, $\angle_{yaw}$=-3.27 ± 3.07º. (M ± SD) Standard: Result= 45.8 ± 5.53 m; V_0= 18.2 ± 1.35 m/s; $\angle_0$= 32.3 ± 3.62º;	Greater throw distances were largely attributable to greater release speeds. The other release parameters where significant differences between groups were found was the yaw angle. With regard to aspects of throwing technique, the increase in release speed with increasing skill across the groups was related to greater run-up speeds and greater peak speeds of the throwing arm

		$\angle_{attack}$=1.83 ± 3.31º, $\angle_{yaw}$=-2.33 ± 2.53º. (M ± SD) Novice: Result= 29.8 ± 3.81 m; V_0= 15.3 ± 1.44 m/s; $\angle_0$= 33.4 ± 5.08º; $\angle_{attack}$=-1.7 ± 1.46º, $\angle_{yaw}$=-9.64 ± 4.9º.	segments relative to center of mass during the delivery stride. The significantly longer acceleration paths for the elite throwers were also important to generate greater release speeds.
(Bennett, Walker, Bissas, & Merlino, 2017a)	3 high speed cameras SONY PXW-FS7 (150 Hz, 1/1250 shutter, ISO: 2000/4000, FHD: 1920x1080 px) to provide 3D footage. Videos imported to SIMI MOTION and manually digitized to obtain kinematic data. All points tracked 15m before the foul line and 10 frames after release. DLT algorithm was used to reconstruct the real-world 3D coordinates from individual camera's x and y image coordinates.	(M ± SD): Result: 84.36 ± 4.17 m; V_0= 27.93 ± 0.71 m/s, H_0= 1.99 ± 0.12 m, $\angle_{attitude}$= 39.58 ± 4.15 º, $\angle_0$= 34.39 ± 2.66 º, $\angle_{attack}$= 5.19 ± 3.65 º, $\angle_{sideslip}$= 14 ± 4.24 º, $\angle_{trunk}$= 58.7 ± 6.82 º, $\angle_{upperarm}$= 47.72 ± 8.49 º, $\angle_{forearm}$= 61.89 ± 6.15 º, $T_{impulse\ stride}$= 361.66 ± 51.47 ms, $T_{delivery\ stride}$= 203.54 ± 38.69 ms, $T_{release}$= 128.77 ± 12.49 ms,	There is a very strong correlation (0.85) between distance thrown and release velocity. However, the data shows that gold medal winner with 28.48 m/s did not generate the fastest release velocity; the bronze medallist produced the fastest release velocity javelin at 29.17 m/s with the 5th placed athlete delivering the second fastest release velocity at 28.55 m/s. Clearly, other key factors influenced how far their respective javelins flew.
(Bennett, Walker, Bissas, & Merlino, 2017b)	3 high speed cameras SONY PXW-FS7 (150 Hz, 1/1250 shutter, ISO: 2000/4000, FHD: 1920x1080 px) to provide 3D footage. Videos imported to SIMI MOTION and manually digitized to obtain kinematic data. All points tracked 15m before the foul line and 10 frames after release. DLT algorithm was used to reconstruct the real-world 3D coordinates from individual camera's x and y image coordinates.	(M ± SD): Result: 63.37 ± 2.36 m; V_0= 24.32 ± 0.99 m/s, H_0= 1.86 ± 0.1 m, $\angle_{attitude}$= 40.73 ± 5.73 º, $\angle_0$= 34.86 ± 3.33 º, $\angle_{attack}$= 6.08 ± 6.05 º, $\angle_{sideslip}$= 8.89 ± 9.07 º, $\angle_{trunk}$= 58.38 ± 5.24 º, $\angle_{upperarm}$= 42.18 ± 14.14 º, $\angle_{forearm}$= 55.16 ± 8.03 º, $T_{impulse\ stride}$= 366 ± 35.83 ms, $T_{delivery\ stride}$= 200 ± 32.46 ms, $T_{release}$= 140.5 ± 12.09 ms, $Dist._{impulse\ stride}$= 1.68 ± 0.25 m, $Dist._{delivery\ stride}$= 1.59 ± 0.21 m	In terms of release velocity, gold medal winner had the highest recorded velocity of the finalists generating 26.42 m/s, this was 1.14 m/s faster than 4th place (28 m/s) and 1.51 m/s quicker than silver medallist who released the javelin at 24.91 m/s. There are many physiological and psychological factors that are unknown or very difficult to quantify that can positively or negatively impact a performance on the day of the competition.
(Best et al., 1993)	2 PANASONIC 1PL high-speed Video Cameras (100 Hz). Peak Performance System was used for calibration. The 3D world coordinate of 18 points was reconstructed using DLT algorithm. The smoothed coordinates were transferred to Peak Performance Technologies 3D Motion Analysis System. Analysis of release, temporal and kinematic parameters.	Men (M ± SD): Result: 80.45 ± 6.7 m; V_0= 28.4 ± 2.26 m/s Women (M ± SD): Result: 59.29 ± 2.19 m; V_0= 24.47 ± 0.23 m/s	Analysis of javelin throw kinematics from 3D perspective provides a far more detailed assessment of technique than the 2D. The majority of release parameters values of 2D and 3D are similar. However, other important parameters, such as sidleslip, cannot be assessed with 2D analysis.
(Campos et al., 2004)	2 synchronized SVHS Panasonic Video Cameras (50 fps). 3D	(M ± SD): Result: 86.46 ± 2.32 m; V_0= 29 ± 0.63 m/s, H_0= 1.97	Each athlete has its particular technique, timings and individualities. Nevertheless,

	photogrammetric analysis. Modulated reference system for spatial calibration. Kinescan 8.3 (IBV) software for the digitizing.	± 0.13 m, $\angle_{attitude}$= 36.34 ± 5.36 º, $\angle_0$= 33.5 ± 4.11 º, $\angle_{attack}$= 2.84 ± 5.31 º	these individual patterns are conditioned by efficient filters. There are minimum requirements needed to throw the javelin at a long distance. All individualities affect the kinetic chain at the final release phase. The aspects that distinguish the best thrower from the other is that he throws in a more rectilinear way and at higher position. His path of acceleration is also longer, and his release conditions are more appropriate.
(Campos et al., 2002)	2 synchronized S-VHS Video Cameras (50 fps). 35 variables were analysed and compared between groups. 3D photogrammetric technique.	World Class >80 m (M ± SD): Result: 86.45 ± 2.31 m; V_0= 28.91 m/s, H_0= 1.97 m; National <75 m (M ± SD): Result: 68.39 ± 2.78 m; V_0= 24.80 m/s, H_0= 1.90 m Significant statistical differences in: V_0, $V_{peak\ elbow}$, $V_{peak\ shoulder}$, Shoulder/hip axis rotation at release, $\angle_{righ\ knee\ at\ release}$, H_0, $V_{vertical\ at\ release}$, $V_{horizontal\ at\ release}$, $\angle_{elbow\ at\ delivery}$	The major differences occur at the final throw phases. World class athletes have a greater ability to use power of the body to accelerate the javelin. When compared with Spanish athletes, world class group evidenced ↑javelin speed, ↑shoulder and elbow speed, ↑rotation lines of hips and shoulders, ↑extension of elbow at release, ↑throw position, ↑increase of speed on the final phases
(Campos et al., 1994)	2 high speed cameras (200f fps). The DLT was used to calculate 3D coordinates. This study includes mechanical variables (position and velocity of the markers, left knee angle, shoulder as hip lines in the horizontal plane) and statistic variables (discrete sets of data to the value of the variable in different throws).	The only significant value corresponds to the negative index between T_1 and T_2 – r= 0.67, p=0.004 T_1 – corresponds to the moment when the left foot touches de ground at the beginning of the final throwing phase; T_2 – corresponds to the moment where the tense arch is generated.	In order to improve performance, the athlete should: on one hand, try to get the tense arch position as soon as possible and, on the other hand, try to make the last phase of the moment as long as possible.
(Hassan, 2015)	Simulation system: steel rods, litter sled, LAVEG laser velocity device and DAS3 software. V_0 (release velocity), acceleration due to gravity and correlate this with a predicted distance.	$r_{release\ velocity}$ = 0.84	The introduction of information technology into the sports performance environment appears to be a positive, although not always essential, step towards achieving an effective and efficient way of learning
(Hussain & Bari, 2012)	1 Video Camera Legaria CANON (50 Hz), placed perpendicularly to the runway. Correlation between release parameters, pull distance, pull time, segment angles, with thrown distance.	$r_{initial\ velocity}$ = 0.764; p< 0.001 $r_{pull\ distance}$ = 0.415; p< 0.001 $r_{approach\ run\ v.}$ = 0.722; p< 0.001 Insignificant r_{Ho}, $r_{\angle 0}$, $r_{\angle\ attack}$	To improve javelin's performance, authors advice an achievement of positive acceleration during running approach, an effective thrusting with the right leg on the penultimate stride, and carry the javelin with an optimal angle on the last strides
(Ito, Ishikawa, Isolehto, Komi &	2 video cameras (200 fps for Japanese and 60 fps for the World Championships). 24 reference	non-significant correlations were obtained between the distance thrown and the	Elite athletes compared with the Japanese: approach with faster velocity and keep the front knee angle in the

Murakami, Tanabe, 2006)	landmarks on each athlete's body and three reference landmarks on the javelin were digitized and the 3D coordinates was calculated using DLT.	release angle, attitude angle, attack angle and release height The pull distance was correlated positively and significantly with the distance thrown ($r = 0.426$, $p < 0.01$; Figure 7), but the pull time was negatively correlated ($r = –0.418$, $p < 0.01$; Figure 8).	extended position during the final phase of throw to change the approach velocity into the forward rotation of trunk. During the forward rotation of the trunk, they also keep their elbow joint angle small and adduction-abduction angle of the shoulder also small to be able to effectively transfer the internal rotation velocity of the shoulder joint to the grip velocity.
(Jung et al., 2012)	3 high speed digital cameras - CASIO EX-F1 (300 fps). The DLT with Kwon3D software (version 4.0) was used to obtain 3D coordinates of 21 body landmarks and 3 javelin landmarks. The study analysis temporal and velocity variables, inclination angles of body segments and length.	(M ± SD): Result= 65.55 ± 4.71 m, V_0= 25.6 ± 1.16 m/s, H_0= 1.86 ± 0.05 m, $\angle_{attitude}$= 40.4 ± 4.3 º, $\angle_0$= 38 ± 2 º, $\angle_{attack}$= 3.7 ± 1.1 º, $Dist._{crossover\ stride}$= 1.88 ± 0.31 m, $Dist._{delivery\ stride}$= 1.53 ± 0.21 m, $T_{crossover\ stride}$= 350 ± 066 ms, $T_{delivery\ stride}$= 198 ± 039 ms, $T_{release}$= 138 ± 013 ms	The amount of time taken at the delivery phase may be a critical factor to enhance javelin throw performance. Therefore, a javelin thrower would need to carry out the right amount of step distance, having a continuous rhythmical run-up. Since the trunk position at release pays a great role in V_0 and H_0, a javelin thrower should not rely only in upper extremities.
(Kaur & Deol, 2016)	One Digital Video Camera, specialized motion software – QUINTIC COACHING 4.01 v17. Correlate linear acceleration of the wrist joint and horizontal velocity of the elbow joint with the throw length	(M ± SD) Result= 44.72 ± 3.46 m $r_{linear\ acc.\ wrist}$ = -0.7 $r_{horizontal\ v.\ elbow}$ = -0.5	Significant relationship between linear acceleration of the wrist joint and performance, as well as the horizontal velocity of the elbow
(Komi & Mero, 1985)	1 LOCAM camera (200 fps). The film was digitized with the Vanguard and Lafayette film analyzers. 14 rigid body segments and the javelin were stablished to study.	Female (M±SD): Result= 64.45 ± 5.71 m; $\angle_{attitude}$= 38 ± 5 º, $\angle_0$= 42 ± 6 º, $\angle_{attack}$= -4 ± 6 º, $V_{horizontal}$= 16.2 ± 1.79 m/s^{-1}, $V_{vertical}$= 19.55 ± 1.63 m/s^{-1}, $V_{resultant}$= 21.86 ± 1.09 m/s^{-1} Male (M±SD): Result= 82.54 ± 4.07 m; $\angle_{attitude}$= 41 ± 9 º, $\angle_0$= 38 ± 4 º, $\angle_{attack}$= 2 ± 12 º, $V_{horizontal}$= 21.3 ± 1.6 m/s^{-1}, $V_{vertical}$= 17.1 ± 1.76 m/s^{-1}, $V_{resultant}$= 27.36 ± 1.68 m/s^{-1}, $r_{release\ velocity\text{-}throw\ distance}$= 0.97 $p<0.001$.	Small biomechanical differences between good and poorer performers were identified. The results can be used to recognize some new criteria for successful performance in javelin throw.
(Kunz & Kaufmann, 1983)	1 highspeed LOCAM Camera (16 mm, 102 fps). Cyclograms analysed on a Vanguard Film Analyser which transferred the coordinates measurements to Hewlett Packard Digitiser. 74 variables were correlated with the throwing distance	(M±SD): Result= 53.47 ± 6.47 m; r_{V0}= 0.757, $r_{\angle carry\ –T5}$= -0.516, $r_{\angle carry\ –\ T6}$= -0.67, $r_{\angle attack}$= -0.604	During running acceleration there's a great build-up of torques at the ankle, knee, hip and intervertebral joints which culminate during the final leg thrust and throw. Therefore, these joints are susceptible to possible injury. Authors suggest a training program adapted to control these joints.
(Lehmann, 2010)	1 DV camera and 1 analagous camera were synchronised (50 Hz).	Female: Result= 61.08 m, V_0= 24.6 m/s, r=0.53; $\angle_0$= 34.6 º,	The correlation between throwing distance and release velocity is highly

	All the valid throws were analysed. The distances were calculated just for the 9 finalists in their best attempts.	r=0.09; $\angle_{attitude}$= 41 º, $\angle_{sideslip}$= 10.8 º, $Dist._{impulse\ stride}$= 1.89 m, $Dist._{delivery\ stride}$= 1.81 m Male - Places 1-3: Result=86.11 m, V_0= 29.3 m/s, $\angle_0$= 35.3 º, $\angle_{attitude}$= 37.5 º, $\angle_{sideslip}$= 12.5º, $Dist._{impulse\ stride}$= 2.36 m, $Dist._{delivery\ stride}$= 1.84 m $T_{impulse\ stride}$= 320 ms, $T_{delivery\ stride}$= 193 ms, $T_{release}$= 93 ms. Places 4-11: Result= 80.46 m, V_0= 28.9 m/s, $\angle_0$= 32.8º, $\angle_{attitude}$= 36.9º, $\angle_{sideslip}$= 14.1º, $Dist._{impulse\ stride}$= 2.09 m, $Dist._{delivery\ stride}$= 2.00 m $T_{impulse\ stride}$= 268 ms, $T_{delivery\ stride}$= 195 ms, $T_{release}$= 105 ms,	significant, but slightly lower than expected. There is no correlation between throwing distance and angle of release.
(Leigh et al., 2013)	2 HD Digital Video Cameras (59.94 fps) (placed behind and on the side of the runway). Manually digitized 24 body and javelin landmarks to obtain 2D coordinate data. DLT was used to produce 3D data.	Female: Results from 42.16-66.67 m; V_0= 23 ± 1.4 m/s; $\angle_0$= 33 ± 3º Male: Result from 60.61-91.29 m; V_0= 27.2 ± 1.1 m/s; $\angle_0$= 34 ± 3º	Greater shoulder and elbow forces and torques may be associated with injuries. For variables that imply greater forces and torques, athletes should do a proper injury prevention work.
(Liu et al., 2010)	2 HD video cameras (60 fps, 1/1000 shutter) filming the last cross-steps and the delivery stride. Data collected during 2007 and 2008 USA Track & Field Outdoor National Champ. The best trial of each athlete was used. 2D analysis with DLT for real time 3D coordinates.	Upper extremity's sequence of female athletes: 1. Upper trunk forward rotation; 2. Right foot touchdown; 3. Left foot touchdown; 4. Shoulder abduction; 5. Shoulder horizontal adduction, elbow extension, shoulder internal rotation; 6. Wrist flexion, release of javelin. Upper extremity's sequence of male athletes: 1. Upper trunk forward rotation; 2. Right foot touchdown; 3. Left foot touchdown, shoulder horizontal adduction; 4. Shoulder abduction; 5. Elbow extension, shoulder internal rotation; 6. Wrist flexion, release of javelin.	Beginnings of upper extremity segments and joint angular motions of elite javelin throwers don't follow a proximal-to-distal sequence, unlike maximum upper extremity joint center linear velocities as suggested in literature for javelin throwing. Male and female employed different sequences of lower and upper extremities.
(Liu et al., 2014)	2 HD video cameras (60 fps, 1/1000 shutter) filming the last cross step and the delivery stride. Calibration frame with 24 control points indicated by Peak Performance system (Englewood,	Duration of single support and delivery (M±SD): Short distance $group_{female}$= 0.383 ± 0.033; Short distance $group_{male}$= 0.367 ± 0.029; Long	Javelin throwers in short and long distance employed similar sequences of initiations of trunk and arm angular motions and maximum angular velocities. The opposite happens between male and female athletes, describing different parameters.

	EUA). 21 critical body landmarks, front edge of the grip, the tail and tip of the javelin. MOTUS videographic data acquisition system for 2D. Linear transformation from 2D to 3D.	distance $group_{female}$= 0.378 ± 0.031; Long distance $group_{male}$= 0.354 ± 0.044.	The sequence of initiations of trunk and arm angular motions and the sequence of maximum angular velocities in javelin throwing are different.
(Mero et al., 1994)	2 NAC Cameras placed back and sideward (100 fps). 18 segments and 20 points were defined (body and javelin). The DLT was used to calculate 3D coordinates of digitized body and javelin landmarks.	Female M±SD): Result= 60.5 ± 4.04 m; H_0= 1.75 ± 0.06, $\angle_0$=34 ± 4º, $\angle_{attitude}$=40 ± 5º, $\angle_{attack}$=6 ± 7º, $V_{0\text{-}horizontal}$=18.7 ± 2.4 m/s, $V_{0\text{-}vertical}$= 12.8 ± 1.4 m/s, $V_{0\text{-}lateral}$=-3.1 ± 2.3 m/s, $V_{0\text{-}resultant}$=23 ± 1.9 m/s, Last step length=1.5 ± 0.1 m, $T_{1st\ contact\ to\ DS}$= 210 ± 37 ms, $T_{DS\ to\ release}$= 141 ± 13 ms, $Pull_{distance}$= 1.57 ± 0.1 m Male (M±SD): Result= 80.47 ± 4.21 m; H_0= 1.81 ± 0.04, $\angle_0$=32 ± 3º, $\angle_{attitude}$=31 ± 6º, $\angle_{attack}$=-1 ± 6º, $V_{0\text{-}horizontal}$=23.9 ± 0.9 m/s, $V_{0\text{-}vertical}$= 14.9 ± 1.5 m/s, $V_{0\text{-}lateral}$=-0.8 ± 2 m/s, $V_{0\text{-}resultant}$=28.3 ± 0.9 m/s, Last step length=1.8 ± 0.1 m, $T_{1st\ contact\ to\ DS}$= 221 ± 22 ms, $T_{DS\ to\ release}$= 135 ± 12 ms, $Pull_{distance}$= 1.8 ± 0.11 m	Both men's and women's grip of javelin and body center of mass exhibited a curved pathway to the right from the left foot during the final foot contact. The position of the body center of mass decreased at the beginning of the final foot contact, but after decrease period it began to increase. Simultaneously with the increase, the peak joint center speed occurred in a proper sequence from proximal to distal segments and finally to the javelin at release. Release speed correlated significantly with the throwing distance in both genders.
(Morriss, Bartlett, & Fowler, 1997)	2 Photosonics 1PL high speed cine cameras (100 Hz or 200 Hz). All the coordinates were digitized by projecting the frame onto a TDS HR48 digitising tablet interfaced to an Acorn Archimedes 440 microcomputer running software. The three-dimensional world coordinates of the eighteen points, defining a 14 segments performer model, plus the tip, grip and tail of the javelin were reconstructed using DLT algorithm.	(M±SD): Result= 81.89 ± 3.54 m, V_0= 28.78 ± 0.8 m/s, $\angle_0$= 38 ± 2.17 º, H_0= 1.97 ± 0.13 m, $\angle_{attack}$= -3.42 ± 3.53 º, $\angle_{sideslip}$= 7± 4,47º	The medalists were able to achieve the higher release speeds. A very good understanding of an athlete's javelin throwing technique is needed to design specific training exercises. Otherwise, the muscles that the athlete uses to apply force to the javelin may not receive the appropriate training stress and, consequently, not aid the thrower's performance.
(Panoutsakopoulos & Kollias, 2013)	1 stationary JVC GR-D720E digital video camera (50 fps, shutter speed of 1/4000). A single camera set-up was used since 2D methods have been found adequate. 2D-DLT where x-axis was parallel to the runway and the y-axis perpendicular and vertical to the x-	(M±SD, r): Result: 59.22 ± 4.42 m; V_0= 22 ± 0.8 m/s, r= 0.909; H_0= 1.8 ± 0.08 m, r= 0.225; $\angle_{attitude}$= 41 ± 5.2 º, r= -0.02, $\angle_0$= 36 ± 3.9 º, r= -0.231, $\angle_{attack}$= 5 ± 6.7 º, r=0.116; $T_{delivery\ stride}$= 0.201 ± 0.031 s, r= -0.196; $T_{release}$= 0.134 ± 0.018	Release velocity was found highly correlated with the throwing distance. Also, the support knee angle has a significant correlation with the performance outcome. These findings suggest that the distance of the throw is highly enhanced by the speed implemented on the javelin at the release.

	axis. 26 throws analyzed and 22 anatomical body points digitized.	s, r= -0.286; $T_{delivery\ phase}$= 0.335 ± 0.033 s, r= -0.284; $Dist._{delivery\ stride}$= 1.40 ± 0.14 m	
(Panoutsakopoulos, Vujkov, Kotzamanidou, & Vujkov, 2016)	2 JVC Digital Video Cameras (100 fps) (behind and on the side of the runway). Data collected during competition with 12 reference markers to produce 2D coordinates with 2D-DLT analysis. Spatial parameters: delivery stride length, distance to foul line, right knee angle, etc. Release parameters: V_0, H_0, $\angle_0$, $\angle_{attack}$	(M±SD): Result: 46.43 ± 4.89 m; V_0 = 16 ± 1.4 m/s; H_0 = 2.08 ± 0.1 m; $\angle_0$ = 36.4 ± 5.3 º; $\angle_{attack}$ = 2.1 ± 6.6 º	Confirms the importance of V_0 on the javelin's performance. It is suggested that young javelin throwers training should focus on performing the release of javelin with a better leg braking action and a definitive proximal-to-distal segmental sequence of the throwing side
(Saratlija et al., 2013)	3 VHS (50 fps) cameras placed behind and both sides of the javelin runway. Correlate 17 variables with throw length	(M±SD): Result= 67.27 ± 3.94 $r_{release\ speed}$ = 0.9 $r_{fast\ front\ sup.\ leg}$ = 0.4	Javelin release speed has the most important role, followed by fast front support leg. The results can be used in kinesiology practice, especially in the process of young throwers technique learning
(Viitasalo et al., 2003)	Photocell gate to measure release parameters almost in real time. The gate consists of 2 infrared invisible walls two meters apart, perpendicular to the throwing direction. The correlation between some parameters and the result was calculated.	(M ± SD, r) Male: Result= 79 ± 2.91 m; V_0= 27.1 ± 0.7 m/s, r= 0.750; $\angle_0$= 32.7 ± 2.6 º, r= -0.750; $\angle_{attack}$= 2.3 ± 4.8 º, r= -0.145. Female: Result= 59.04 ± 2.6 m; V_0= 23 ± 0.7 m/s, r= 0.780; $\angle_0$= 31.7 ± 2.5 º, r= -0.216; $\angle_{attack}$= 6.6 ± 6.9 º, r= -0.033.	Release speed was found to have the highest correlation with the result.
(Whiting, Gregor, & Halushka, 1991)	1 high speed camera PHOTOSONICS (100 fps, 16 mm). Serial film frames were digitized with NUMONICS 1200 (IBM PC-XT) to provide location of the javelin's tip, grip and tail and the athlete's elbow, shoulder, hip, knee and ankle.	Result= 75.84 ± 3.32 m, $\angle_0$= 36 ± 4 º, $\angle_{attack}$= 1 ± 5 º, $\angle_{attitude}$= 37 ± 5 º, V_0= 29.6 ± 1.8 m/s, V_{elbow}= 7.9 ± 1.1 m/s, $V_{shoulder}$= 4.8 ± 0.8 m/s, V_{hip}= 2.9 ± 0.6 m/s, $Dist._{last\ step}$= 1.73 ± 0.14 m, $T_{1st\ contact\ to\ DS}$= 224 ± 17 ms, $T_{DS\ to\ release}$= 115 ± 12 ms	Careful individual assessment is required, specially at elite level. The complexity of the event and particular sensitivity of the final result demands it.

**r* – correlation; *p* – statistical significance; V – velocity; Sup. – superior; V_0 – release velocity; H_0 – release height; $\angle_0$ – release angle; Dist. – distance; T – time; DS – double support; DLT – direct linear transformation, 3D – three dimensional, 2D – two-dimensional, fps – frame per second.

Table 3 – *Main parameters results overview*

Parameter		Male Non-elite (M ± SD)	Male Elite (M± SD)	Female Non-elite (M ± SD)	Female Elite (M± SD)	References
Distance (m)		50.84 ± 13.6	81.22 ± 4.01	34.83	60.98 ± 2.35	Aleksić-Veljković et al. (2012); Bartlett et al. (1996); Bennett et al. (2017a); Bennett et al. (2017b); Best et al. (1993); Campos et al. (2004); Campos et al. (2002); Kaur and Deol (2016); Komi & Mero (1985); Kunz and Kaufmann (1983); Mero et al., (1994); Morriss et al. (1997); Panoutsakopoulos and Kollias (2013); Saratlija et al. (2013); Panoutsakopoulos et al. (2016); Viitasalo et al. (2003); Whiting et al. (1991)
Phases Duration	Impulse (ms)	-	316.55 ± 46.93	348.7 ± 1.84	338.67 ± 34.43	Aleksić-Veljković et al. (2012); Jung et al. (2012); Bennett et al. (2017b); Bennett et al. (2017a); Lehmann (2010); Mero et al., (1994)
	Delivery (ms)	-	207.31 ± 14.46	180.1	202.25 ± 5.32	Aleksić-Veljković et al. (2012); Mero et al. (1994); Jung et al. (2012); Panoutsakopoulos and Kollias (2013); Bennett et al. (2017b); Lehmann (2010); Whiting et al. (1991); Bennett et al. (2017a)
	Release (ms)	-	115.35 ± 17.12	153.1	134.7 ± 8.67	Aleksić-Veljković et al. (2012); Mero et al. (1994); Jung et al. (2012); Panoutsakopoulos and Kollias (2013); Bennett et al. (2017b); Lehmann (2010); Whiting et al. (1991); Bennett et al. (2017a)
Phases Length	Impulse (m)	-	2.27 ± 0.14	1.55	1.77 ± 0.13	Aleksić-Veljković et al. (2012); Jung et al. (2012); Bennett et al. (2017b); Lehmann (2010); Bennett et al. (2017a); Mero et al., (1994)
	Delivery (m)	-	1.83 ± 0.1	1.19	1.57 ± 0.15	Aleksić-Veljković et al. (2012); Mero et al. (1994); Jung et al. (2012); Panoutsakopoulos and Kollias (2013); Bennett et al. (2017b); Lehmann (2010); Whiting et al. (1991); Bennett et al. (2017a)
Release Velocity (m/s)		18.58 ± 4.33	28.24 ± 0.87	17.42	23.53 ± 1.27	Panoutsakopoulos et al. (2016); Bartlett et al. (1996); Aleksić-Veljković et al. (2012); Leigh et al. (2013); Viitasalo et al. (2003); Bennett et al. (2017a); Komi & Mero (1985); Mero et al. (1994); Best et al. (1993); Morriss et al. (1997); Lehmann (2010); Campos et al. (2004); Whiting et al. (1991); Panoutsakopoulos and Kollias (2013); Bennett et al. (2017b); Jung et al. (2012); Campos et al. (2002)
Release Height (m)		1.99 ± 0.13	1.94 ± 0.08	1.89	1.82 ± 0.06	Panoutsakopoulos et al. (2016); Aleksić-Veljković et al. (2012); Mero et al. (1994); Bennett et al. (2017b); Jung et al. (2012); Campos et al. (2002); Bennett et al. (2017a); Campos et al. (2004)

Angle	Release (º)	36.4	34.38 ± 2.22	44.20	35.52 ± 3.28	Panoutsakopoulos et al. (2016); Aleksić-Veljković et al. (2012); Mero et al. (1994); Campos et al. (2004); Leigh et al. (2013); Bennett et al. (2017a); Bennett et al. (2017b); Jung et al. (2012); Komi & Mero (1985); Lehmann (2010); Panoutsakopoulos and Kollias (2013); Viitasalo et al. (2003)
	Attitude (º)	-	36.98 ± 3.84	43.7	39.93 ± 1.36	Aleksić-Veljković et al. (2012); Komi & Mero (1985); Jung et al. (2012); Mero et al. (1994); Bennett et al. (2017b); Panoutsakopoulos and Kollias (2013); Campos et al. (2004); Whiting et al. (1991); Bennett et al. (2017a)
	Attack (º)	2.1	2.06 ± 2.05	0.9	3.89 ± 4	Panoutsakopoulos et al. (2016); Aleksić-Veljković et al. (2012); Komi & Mero (1985); Jung et al. (2012); Mero et al. (1994); Bennett et al. (2017b); Panoutsakopoulos and Kollias (2013); Campos et al. (2004); Whiting et al. (1991); Bennett et al. (2017a); Viitasalo et al. (2003)
	Sideslip (º)	-5.99 ± 5.17	8.87 ± 7.38	-	9.85 ± 1.35	Bartlett et al. (1996); Bennett et al. (2017a); Bennett et al. (2017b); Lehmann (2010); Morriss et al. (1997)

1.3.2. Methodological Quality Score

Quality assessment scores of the 26 papers included ranged from 9 to 13, reaching an average score of 11.42 out of 17. This value indicates a high methodological quality of the articles included on the present review (Table 1).

1.4. Discussion

On the past few decades, sports sciences have been focusing on optimizing the javelin throw's technique as well as its training methods (Hassan, 2015). The evaluation of elements which define a technical pattern of each athlete is a crucial step in sports training (Campos et al., 1994). Interests in the complex javelin's technique has led the modern analysts to develop methods in order to provide coaches and athletes a more flexible way to view the throw (Best et al., 1993). In the past few years, the research on javelin throwing biomechanics has basically focused on the throwers' technique and on the aerodynamics of the instrument. The experimental designs on javelin throw kinematics are predominantly established throughout video recordings and 2D or 3D motion analysis (Viitasalo et al., 2003). The present review summarizes the literature that's surrounding the javelin throw analysis. Thus, the biomechanical description of kinematic parameters its explored in several studies by analysing elite male athletes (Bennett et al., 2017a; Campos et al., 2004, 1994; Morriss et al., 1997; Saratlija et al., 2013; Whiting et al., 1991), non-elite male athletes (Hassan, 2015; Hussain & Bari, 2012; Kaur & Deol, 2016; Panoutsakopoulos et al., 2016), elite/non-elite women athletes (Aleksić-Veljković et al., 2012; Bennett et al., 2017b; Jung et al., 2012; Panoutsakopoulos & Kollias, 2013), both genders (Best et al., 1993; Komi & Mero, 1985; Leigh et al., 2013; Liu et al., 2010, 2014; Mero et al., 1994; Viitasalo et al., 2003) or comparing different skill levels (Aleksić-Veljković et al., 2012; Bartlett et al., 1996; Campos et al., 2002; Kunz & Kaufmann, 1983). Also, different methods are register by using distinct ways to record and process the data. While some studies choose for 2D analysis (Aleksić-Veljković et al., 2012; Panoutsakopoulos & Kollias, 2013; Panoutsakopoulos et al., 2016) since they found this method to be adequate for evaluating basic javelin parameters, another studies choose the 3D analysis (Bennett et al., 2017b, 2017a; Best et al., 1993; Campos et al., 2004, 2002, 1994; Leigh et al., 2013; Liu et al., 2010, 2014; Mero et al., 1994; Morriss et al., 1997) to improve technique feedback by getting a far more detailed evaluation of technique (Best et al., 1993). Hence, the three-dimensional method have an important role analyzing parameters, such as sideslip, which cannot be analyzed in 2D (Bartlett et al., 1996). There is no record of studies where wearable sensors are used to study javelin's throw performance. The biomechanics has mostly been investigated the final throw phases, especially the implement release parameters (Viitasalo et al., 2003). According to Bartonietz (2000), the distance thrown is, to a large degree, determined by the release velocity, the height of release and the angle of release, which means the direction of the velocity of release. Accordingly, the reviewed articles report that the most commonly analyzed kinematic parameters are release velocity, release height, sideslip, attitude, attack and release angles, duration and distance of the steps/phases (see Table 3).

1.4.1. Impulse, delivery and release phase

The javelin approach run, including the impulse stride, has the role to create optimal conditions for delivery (Bartonietz, 2000). By definition, to a right-handed athlete, the impulse stride is considered the moment from the penultimate left foot to the final right foot contact (Bennett et al., 2017a). Moreover, literature frequently analyzes the duration and the length of the impulse stride, which implies an important role in those parameters. Regardless the individual technical characteristics, all coaches and athletes should aim to develop a method intending to improve efficiency by reducing the velocity loss after planting the rear foot (Bartonietz, 2000). According to literature, longer throws are achieved with higher speed and longer impulse strides. Another important instant, which is also part of the approach-run and contributes in a large scale to the release speed, is the delivery stride, also known as bracing stride (Bartlett & Best, 1988; Bartonietz, 2000). At this moment, the javelin is accelerated to maximum speed and then the release of the implement happens (Liu et al., 2010). According to Bartonietz (2000), the delivery phase is described as the movement following the moment of planting the rear leg, after the impulse stride, until the implement's release. However, is often seen in literature the separation of this phase in two distinct sub phases - the delivery and the release phase. Thus, the delivery phase is the moment from the final right foot contact to the final left foot contact and the release lays from the time of the final left foot contact until the javelin's release (Bennett et al., 2017a). A desirable flat planting of the last left foot contact demands a long delivery stride. Consequently, less-qualified throwers, in comparison with more qualified athletes, tend to have shorter delivery strides with steeper ground reaction forces (Menzel, 1986). A longer delivery stride contributes to a better use of inertial forces and enhances performance (Aleksić-Veljković et al., 2012). An additional concept is mentioned by Jung et al. (2012) called power stride. The power stride is attained when the delivery stride holds a wide base and efficiently sends power from the ground to the javelin (Jung et al., 2012). According to the literature available on this review, a study performed by Hussain and Bari (2012) indicates that the approach run velocity as a correlation of 0.722 ($p<0.001$) with the thrown distance. Therefore, it becomes important to analyze the duration of the phases, specially the impulse, the delivery and the release. According to Aleksić-Veljković et al. (2012), female national level Serbian athletes evidenced an impulse stride duration of 347.4 ± 42.40ms with a length of 1.55 ± 0.33m. Additionally, the elite level women athletes, at the World Championship 2011 (Daegu), presented a stride duration of 350 ± 0.66ms and a distance of 1.88 ± 0.31m (Jung et al., 2012). Recently, at the World Championships in London (2017), women finalists performed an average impulse stride duration of 366 ± 35.83ms with a length of 1.68 ± 0.25m (Bennett et al., 2017b). According to the studies contained on this review, the greater average impulse stride distance was documented by Lehmann (2010) at 2009 World Championships with 1.89 ± 0.2m. Giving Liu et al. (2010) analysis between elite foreign and top Serbian athletes, the length of the impulse stride is approximately the same in both groups (1.64 ± 0.18m and 1.55 ± 0.32m), however, the duration of the impulse is shorter in elite throwers (0.3 ± 0.03s and 0.35 ± 0.04s) although there's no significant statistical difference. Regarding men competitors, Bennett et al. (2017a) showed an average impulse stride duration of 361.66 ± 51.47ms with a distance of 2.20 ± 0.36m. At the 2009 World Championship, Lehmann (2010) analysis showed that, from 1-3 place, the average duration and distance was 320ms and 2.36m, respectively. From the 4-11 place, the average duration and distance was 268ms and 2.09m. Speaking about the delivery stride length and duration in female athletes, non-elite Serbian throwers reported 1.19 ± 0.21m of length and a duration of 180.1 ± 37.71ms (Aleksić-Veljković et al., 2012). These values are clearly lower than the ones presented by the elite throwers presented in several articles. At the Barcelona's Olympic Games in 1992, women finalists showed an average delivery step length of 1.5 ± 0.1m and a duration of 210 ± 37ms (Mero et al., 1994). Similarly, Jung et al. (2012) reported a duration of 198 ± 39ms and length of 1.53 ± 0.21m; Panoutsakopoulos and Kollias (2013) described a duration of 201 ± 31ms and a length of 1.40 ± 0.14m; and Bennett et al. (2017b) described a duration of 200 ± 32.46ms and a length of 1.59 ± 0.21m. The greatest delivery step length is reported by the female finalists at the 2009 World Championship with 1.81 ± 0.13m (Lehmann, 2010). Curiously, at the 2009 World Championships, three athletes, including the winner and the third place, described an impulse stride bigger than the delivery stride. The second place and the rest of the women finalists evidenced a delivery stride larger than the impulse. The winner (67.50 m) documented an impulse stride of 2.02m and a delivery of 1.73m. On the other hand, the second-place athlete (66. 42m) reported an impulse stride of 1.73m and a delivery of 1.89m. Totally different strides outcomes for similar thrown distances. These evidences corroborate with the principle of individuality where each athlete should find their own recipe (Bartonietz, 2000). Regarding male athletes delivery stride analysis, eight elite throwers were recorded and showed a delivery stride duration of 224 ± 17ms with a length of 1.73 ± 0.14m (Whiting et al., 1991). Higher values are reported by Mero et al. (1994) and Bennett et al. (2017a) with 221 ± 22ms and 1.8 ± 0.1m, 203.54 ± 38.69ms and 1,79 ± 0.27m, duration and length, respectively. On the study performed by Lehmann (2010), the first three places described an average delivery stride duration of 193ms and a length of 1.84m; while the 4-11 competitors reported a duration of 195ms and 2m length. On the women's analysis, it can be seen a great difference between the low-level athletes when compared with the elite. Undoubtedly, elite athletes have bigger stride lengths and, consequently, longer duration. However, the longer durations are just a consequence of the greater stride lengths which doesn't mean that the elite athletes are slower. Previous analysis tells us the opposite (Panoutsakopoulos et al., 2016); Bartlett et al.,1996; Aleksić-Veljković et al., 2012; Leigh et al., 2013; Viitasalo et al., 2003; Mero et al., 1994; Best et al., 1993; Morriss et al., 1997; Lehmann, 2010; Whiting et al., 1991; Jung et al., 2012). To conclude the phases temporal analysis, the release duration is going to be discussed. Female Serbian athletes are the ones that take longer time to perform the release with a duration of 153.1 ± 25.9ms (Aleksić-Veljković et al., 2012) while elite athletes take 141 ± 13ms (Mero et al., 1994), 138 ± 013ms (Jung et al., 2012), 134 ± 18ms (Panoutsakopoulos & Kollias, 2013) and 140.5 ± 12.09ms (Bennett et al., 2017b). According to Aleksić-Veljković et al. (2012), the release duration is shorter among elite throwers when compared with top Serbian athletes (120 ± 30ms and 153.1 ± 25.9ms, respectively). These findings demonstrate that the performance speed of the last, release, phase is higher in elite than top Serbian throwers, which contributes to the achievement of better results (Leigh et al., 2013). Regarding men competitors, Mero et al. (1994) reported a delivery duration of 135 ± 12ms which are similar to the ones presented by Bennett et al. (2017a) at the 2017 World Championships (128.77 ± 12.49ms). Faster release durations are presented by Whiting et al. (1991) elite male athletes (115 ± 12ms) and Lehmann (2010) at the 2009 World Championships where the first 3 athletes evidenced a duration of 93ms and the remaining athletes reported a 105ms duration. There is no available literature giving a detailed analysis on the phases and comparing them between different level athletes. However, according to Campos et al. (2002), world class group revealed a greater increase of speed at the final throw phases (20.08) than the Spanish athletes (15.37), describing a significant statistical difference between both groups ($p<0.00$). According to the release duration values presented on this review, it is noticeable that male throwers take less time releasing the implement than women. Summing up, elite male athletes presented impulse phase duration and length of 316.55 ± 46.93ms and 2.27 ± 0.14m, respectively; a delivery phase duration and length of 207.31 ± 14.46ms and 1.83 ± 0.1m, respectively; and, finally, a release duration of 115.35 ± 17.12ms. Female non-elite athletes demonstrated impulse phase duration and length of 348.7 ± 1.84ms and 1.55m; delivery phase duration and length of 180.1ms and 1.19m; and lastly, a release duration of 153.1ms. Finally, female elite athletes presented impulse phase duration and length of 338.67 ± 34.43ms and 1.77 ± 0.13m; delivery phase duration and length of 202.25 ± 5.32ms and 1.57 ± 0.15m; and a release duration of 134.7 ± 8.67ms (see Table 3).

1.4.2. Release Velocity (V0)

Release velocity is considered the most important parameter which determines the distance achieved by the javelin. The achieved linear velocity of the javelin at release relies on the effectiveness of power transmission from the body to the upper limb and then to the javelin (Campos et al., 2004). In other words, the release speed is a combination of the effective transfer of kinetic run-up energy throughout efficient leg positioning, with the application of the law of mass inertia, allied by the kinetic chain, delivering the energy onto the shoulder area, the elbow and, finally, the wrist. Such kind of action allows a harmonious inter-muscular coordination which is also named stretch reflex action (Komi & Mero, 1985). By defining the kinetic energy given to the implement, the release velocity is the only factor that can be boosted by the athlete's action (Bartonietz, 2000). In this review, several articles mention this parameter in both male and female athletes, acknowledging its importance. According to Panoutsakopoulos et al. (2016), young male javelin throwers evidenced a release velocity of 16 ± 1.4m/s which is similar to the values reported by novice athletes of 15.3 ± 1.44m/s and club level standard athletes of 18.2 ± 1.35m/s (Bartlett et al., 1996). Totally distinctive values are attained by male javelin throwers competing at the USATF Championships from 2007 to 2010 exhibiting 27.2 ± 1.1m/s of release velocity (Leigh et al., 2013). Similar values of 27 ± 0.9m/s were reported by Bartlett et al. (1996) who studied men's javelin throwers competing at AAA National Championships (England); also Komi and Mero (1985) studied the finalists of the 1084 Olympic Games in Los Angeles and the resultant release velocity was 27.36 ± 1.68m/s, similar to the results reported by the infrared photocell gate of 27.1 ± 0.7m/s (Viitasalo et al., 2003). A recent study conducted by Bennett et al. (2017a) presented values slightly higher than the ones presented by the previous studies, screening a release velocity of 27.93 ± 0.71m/s at the IAAF's World Championships 2017 in London. By comparison, the Barcelona Olympic Games (1992) finalists presented greater velocities (28.3 ± 0.9m/s) (Mero et al., 1994); and also, at the World Student Games of 1991 (Sheffield, England), the men documented a release velocity of 28.4 ± 2.26m/s (Best et al., 1993). Similar velocities are described by the finalist of IAAF World Championships of 1995 with 28.78 ± 0.8m/s (Morriss et al., 1997). At Sevilla's Athletics World Championships (1999) the best throw of each finalist was analyzed resulting on a release velocity of 29 ± 0.63m/s (Campos et al., 2004) which is similar to the results presented by the medalists at IAAF's World Championships in 2009 (29.3m/s) (Lehmann, 2010). The highest value on this review was achieved by eight elite male javelin throwers analyzed during competition with values of 29.6 ± 1.8m/s (Whiting et al., 1991). Regarding women competitors, there's less amount of literature in comparison with men. Serbian female athletes were assessed, and analysts reached a value of 17.42 ± 3.74m/s, which was the lowest on this review. This outcome it is highly related with the lower distance thrown average (34.83 ± 6.72m) (Aleksić-Veljković et al., 2012). On an elite level, Komi and Mero (1985) analyzed the finalists of the Los Angeles Olympic Games 1984 and reported a value of 21.86 ± 1.09m/s similar to the results attained by top female javelin throwers of 22 ± 0.8m/s (Panoutsakopoulos & Kollias, 2013). Leigh et al. (2013) reported a release velocity of 23 ± 1.4m/s by analyzing women javelin throwers competing at USATF Championships from 2007 to 2010. Similar to these results, Mero et al. (1994), at the Barcelona's 1992 Olympic Games, documented a release velocity of 23 ± 1.9m/s and also Viitasalo et al. (2003) showed 23 ± 0.7m/s recorded by the infrared photocell gate. The highest values of this parameters are documented by the World Championships finalists of 2017 with a value of 24.32 ± 0.99m/s (Bennett et al., 2017b), by the female athletes studied at the World Student games in 1991 (24.47 ± 0.23m/s) (Best et al., 1993), by the finalists of the 2009 IAAF's World Championships (24.6 m/s) (Lehmann, 2010) and by the World Championships 2011 finalists in Daegu, accomplishing a release velocity of 25.6 ± 1.16m/s (Jung et al., 2012).

Accordingly, there is an evident correlation between the release velocity and the distance thrown. The study performed by Bartlett et al. (1996) shows it perfectly by analyzing three levels of performers – novice, club group and elite. The novice group have the lower release velocity and also the lower distance thrown (29.8 ± 3.81m), followed by the club group which achieved a distance of 45.8 ± 5.53m and, consequently, attained a higher release velocity than the novice athletes. The elite level group demonstrated the higher release velocity and, thus the longer distance thrown (74.4 ± 4.77m). Also, Campos et al. (2002) compared world class and national level javelin throwers which attained 28.91m/s and 24.80m/s, respectively; concluding that there was a significant statistical difference between those groups ($p<0.00$). Several studies have calculated the correlation value between many javelin throwing parameters and compared them with the distance thrown. Specially the release velocity, is the most popular factor among the investigators since it has a huge positive correlation with the distance thrown. Saratlija et al. (2013) reported a correlation of 0.9 and concluded that the javelin release speed has the most important role, followed by fast front support leg. Also, Panoutsakopoulos and Kollias (2013), reported a big correlation of

0.909 by analyzing women athletes and suggest that the distance of the throw is highly enhanced by the speed implemented on the javelin at the release. Another studies also reported great values of correlation like 0.75 (Viitasalo et al., 2003), 0.84 (Hassan, 2015) or 0.757 (Kunz & Kaufmann, 1983). The lower correlation value is presented by (Lehmann, 2010) by analyzing the female finalists at the IAAF's 2009 World Championships (r=0.53). Consequently, elite level athletes are expected to get higher values as it is highly correlated with the throwing distance. Summarizing, release velocity results by levels of performance, non-elite male athletes presented values of 18.58 $\pm$ 4.33m/s, elite male demonstrated an average of 28.24 $\pm$ 0.87m/s; non-elite female athletes presented 17.42m/s and elite female competitors evidenced an average release velocity of 23.53 $\pm$ 1.27m/s (see Table 3).

1.4.3. Release Height (H_0)

This parameter is defined as the vertical distance between the ground and the javelin's mass center at release (Panoutsakopoulos & Kollias, 2013). The release height is conditioned by the thrower's height, lateral bending of the trunk and front leg knee angle at release (Campos et al., 2004). Theoretically, throwers should intent to throw as high as their height allows while keeping the foot contact on the ground (Campos et al., 2004). According to Bartonietz (2000), there's an optimum release height for each athlete's individuality, relaying always on his or her body dimensions and technique. This author believes that, in practice, a high release height is typical of athletes at a low performance level linked to technical mistakes, for example, a relatively high body posture at the beginning of delivery triggered by a steep planted front leg causing the implement being released over an almost vertical left leg. According to Böttcher and Kühl (1998), the release height is mostly determined by the height of the athlete and it has a small effect on the distance thrown. Yet, it is an indication of a favorable body posture. In this review, the article by Panoutsakopoulos et al. (2016) presents data from young Serbian javelin throwers which demonstrated a release height of 2.08 meters, expressing 113% of the body height and a low correlation with the distance thrown (r=0.21), a percentage rather higher than the one documented by Böttcher and Kühl (1998) (105%). In male elite level athletes, at the 1992 Barcelona Olympic games, finalists described an average of 1.81 meters of release height (Mero et al., 1994). The winner (body height: 1.86m) displayed his best throw (88.18m) with a release grip height of 1.83m (Mero et al., 1994) which was similar to the height at the Sevilla's 99' World Championship where he threw 87.67m at a release height of 1.80m (Campos et al., 2004). Eight years later, at the IAAF's World Championships in London, Bennett et al. (2017a) reported a release height average of 1.99 ± 0.12m where the winner (body height: 1.88m) threw 89.89m at a 1.94m height and the last place athlete (body height: 1.75m) threw his best (76.29m) at a 1.76m height. Morriss et al. (1997) also reported a release height of 1.97 ± 0.13m among the finalists. Campos et al. (2004), at the World Athletics Championships in Sevilla 1999, reported an average release height of 1.97 ± 0.13m, where the winner threw his best (89.52m) with a release height of 2.14 meters and the last place athlete (83.84m) threw his best at a similar height of 2.08 meters. The same data base was used by Campos et al. (2002) to stablish a comparison with Spanish javelin throwers that released at a height of 1.90 meters, revealing a significant statistical difference of p=0.021 when related with Sevilla's 99' finalists.

Regarding women athletes, at the Barcelona's 1992 Olympic Games, the finalists attained an release height average of 1.75 ± 0.06m (Mero et al., 1994). More recently, at the IAAF's World Championships 2017, the winner (body height: 1.82m) threw her best (66.76m) at a release height of 1.92m and the last place thrower (body height: 1.85m) threw 60.12m at 1.96m height (Bennett et al., 2017b). At this competition, the average release height of the finalists was 1.86 ± 0.1m. Jung et al. (2012) analysed the finalists at the 2011 World Championships (Daegu) and reported an average release height of 1.86 ± 0.05m. At this competition the winner threw 71.99m at a release height of 1.85m and the last place threw 59.27m at 1.86m height. Aleksić-Veljković et al. (2012), utilized the same data base to compare world class athletes with club level Serbian athletes (average release height: 1.89 ± 0.1m) reporting a significant statistical difference between groups (p= 0.04). However, on this study data base, authors used only the best three competitors of the Daegu 2011 World Championships which directly affects the release height average. In other words, the average with the best three stands at 1.74 ± 0.1m and with all the finalist describes a 1.86 ± 0.05m height. Consequently, it becomes delicate to compare and stablish a significant difference between those two groups of athletes. Accordingly, in this review, studies defend that there's no significant correlation between release height and distance thrown (Hussain & Bari, 2012; Panoutsakopoulos & Kollias, 2013). Campos et al. (2002) demonstrates that elite throwers release the implement from a higher position than national level athletes, however, it should be taken into account that the release height is conditioned by the athlete's size which means that some corrective function should be applied in order to normalise the results. Nevertheless, as said previously on this review, the release height is not only conditioned by the athlete's size but also by the body segments actions performed during the final phase (Campos et al., 2004). According to Campos et al. (2002), it could be recognized that the international athletes throw from a higher position due to the technical execution more than to the anthropometrical differences of each throwers group. Although investigators aim to describe a technique pattern according to skill level, they acknowledge that the release height depends on the individuality of each athlete by adapting their behaviour to their physique and technique. The delivery phase implies a great technical execution and, although world class athletes expected to be taller, their enhanced position "under the javelin" it's as low as their body allows to potentiate the energy transference to the javelin. That's why lower level athletes are expected to exhibit a higher position since their technique is not that refined. In conclusion, it seems to be impossible to draw a pattern when it comes to release height. Each athlete adapts their behaviour to its body type/condition and its technique in order to potentiate its performance. Summing up the release height results according to skill level, non-elite male athletes presented values of 1.99 ± 0.13m, elite male demonstrated an average of 1.94 ± 0.08m; non-elite female athletes presented 1.89m and elite female competitors evidenced an average release height of 1.82 ± 0.06m (see Table 3).

1.4.4. Attack, release and attitude angle and sideslip

1.4.4.1. The release angle

Another parameter mentioned often in literature is the release angle which is defined as the angle between the velocity vector (direction of the travel) and the horizontal reference at release (Bartlett et al., 1996; Best et al., 1993; Komi & Mero, 1985; Panoutsakopoulos & Kollias, 2013). This angle is reported by Kunz and Kaufmann (1983) as one of the primary factors that dictate the distance thrown. According to the literature available, some authors define the optimum release angle between 33-36º (Best et al., 1993; Böttcher & Kühl, 1998; Mero et al., 1994) and others place the optimal range in between 32º and 37º (Campos et al., 2004). A study performed by Panoutsakopoulos et al. (2016) with young Serbian club level athletes, showed an average release angle of 36.4 ± 5.3º. On an elite male level, results are heterogeneous since there are studies that report 32 ± 3º (Mero et al., 1994), 33.5 ± 4.11º (Campos et al., 2004), 34 ± 3º (Leigh et al., 2013), 34.39 ± 2.66º (Bennett et al., 2017a) or even 38 ± 4º (Komi & Mero, 1985). Regarding female competitors, results demonstrate a similar diversification. There's no recognized pattern. According to Aleksić-Veljković et al. (2012), female Serbian athletes reported a release angle of 44.2 ± 5.67 º while elite female throwers heterogeneously described release angles of 34.86 ± 3.33º (Bennett et al., 2017b), 38 ± 2º (Jung et al., 2012), 42 ± 6º (Komi & Mero, 1985), 34.6º (Lehmann, 2010), 33 ± 3º (Leigh et al., 2013), 34 ± 4º (Mero et al., 1994), 36 ± 3.9º (Panoutsakopoulos & Kollias, 2013), 31.7 ± 2.5º (Viitasalo et al., 2003). Furthermore, some studies reported the correlation between the distance thrown and the described release angle. Results are also controversial regarding this relationship. According to Panoutsakopoulos and Kollias (2013), the correlation between elite female throwers' release angle and outcome is insignificant, which is similar to the one presented by Ito et al. (2006) with elite athletes and by Viitasalo et al. (2003) with female athletes. However, the same study by Viitasalo et al. (2003) but this time on men athletes, reported a negative correlation (r=0.750), which is substantially higher. Other studies on male and female competitors reported, once again, an insignificant correlation between the two parameters (Hussain & Bari, 2012; Lehmann, 2010). Accordingly, no tendency was observed which suggests that, even though the angle should lay between 33º-36º (Best et al., 1993; Böttcher & Kühl, 1998; Mero et al., 1994), each athlete should address an suitable angle to its own physical individualities. Summarizing the results, non-elite male athletes presented values of 36.4 º, elite male demonstrated an average of 34.38 ± 2.22 º; non-elite female athletes presented 44.2 º and elite female competitors evidenced an average release angle of 35.52 ± 3.28 º (see Table 3).

1.4.4.2. The attitude angle

According to literature, the attitude angle is measured between the long axis of the javelin and the horizontal reference at release (Best et al., 1993; Komi & Mero, 1985; Panoutsakopoulos & Kollias, 2013). It's suggested by Kunz and Kaufmann (1983) that higher attitude angles have an adverse impact on the throw. Moreover, in order to attain a greater distance, it's desirable to have a small attack angle which, by another words, means that the angle of attitude should be slightly higher than the release angle (Menzel, 1986). According to Menzel (1986), low skilled athletes have a tendency to deviate too much the release direction (angle of release) from the javelin direction (angle of attitude). This might be justified by the fact of less skilled athletes normally demonstrate steeper angles of attitude. There's no optimal range described on literature, however, Menzel (1986) suggests that the angle of attitude shouldn't differ more than 8 degrees from the release angle. Also Böttcher and Kühl (1998) says that great differences between the attitude and release angle prevent an optimal energy transference and instigates the javelin's vibration. Thus, these lead to an increase on air's resistance and a decline of air flow during the flight (Böttcher & Kühl, 1998). The theoretical background provides a reasonable explanation for the values presented by the articles on the present review regarding the women's side. Serbian female athletes indicate an attitude angle of 43.7 ± 6.11º (Aleksić-Veljković et al., 2012) while elite athletes normally present lower values like 38 ± 5º (Komi & Mero, 1985), 40º (Jung et al., 2012; Mero et al., 1994), 40.73 ± 5.73º (Bennett et al., 2017b) or 41 ± 5.2º (Panoutsakopoulos & Kollias, 2013).

Regarding men competitors, there are no studies that investigate the differences in attitude angle between distinct skill levels neither studies that have calculated the attitude angle in non-elite competitors. However, the studies on this review display a diversified set of results. In the 1992 Olympic Games, the male athletes attained a attitude angle of 31 ± 6º which is substantially lower than the one presented by Campos et al. (2004) (36.34 ± 5.36º), Whiting et al. (1991) (37 ± 5º), Bennett et al. (2017a) (39.58 ± 4.15º) and Komi and Mero (1985) (41 ± 9º). The correlation between the attitude angle and the distance thrown is also controversial among the articles, since some studies (Hussain & Bari, 2012; Ito et al., 2006; Panoutsakopoulos & Kollias, 2013) find this relationship insignificant but Kunz and Kaufmann (1983) report a negative correlation (r=0.670). However, the picture changes when studies compare men's and women's attitude angle. According to Jung et al. (2012) female medalists of the 2011 IAAF World Championships in Daegu, presented a higher average of release and attitude angle than the male medalists. Mero et al. (1994) also reported a significant difference ($p<0.01$) between men's and women's attitude angle at the 1992 Olympic Games in Barcelona. In conclusion, elite male demonstrated an average of 36.98 ± 3.84º; non-elite female athletes presented 43.7º and elite female competitors described an average attitude angle of 39.93 ± 1.36º (see Table 3).

1.4.4.3. The attack angle

The attack angle is defined as the angle between the javelin's longitudinal axis (x axis) and the angle of release. This angle is measured positively in a counter-clockwise when observed from above (Bartlett & Best, 1988; Bartlett et al., 1996). In a simple way, the attack angle is the difference between the release angle and the attitude angle at release (Bennett et al., 2017a). According to Böttcher and Kühl (1998), it's advisable to attain an angle of attack of zero or as close as possible to this value. This corroborates with Hubbard and Alaways (1987) which say that the attack angle should lay between 0 and 2.5º. However, in the Campos et al. (2004) study, they affirm that theoretical references suggest an attack angle not over ± 8º to perform an effective throw. A study performed on young Serbian amateur athletes presented an attack angle of 2.1 ± 6.6º (Vassilios et al., 2016). In elite male athletes, the finalists of 1984 Los Angeles Olympic Games described an attack angle of 2 ± 12º (Mero et al., 1994), which is similar to the one presented by Campos et al. (2004) (2.84 ± 5.31º) and by Viitasalo et al. (2003) (2.3 ± 4.8º). Slightly lower values were presented by the male finalists in 1992 Barcelona's Olympic Games of -1 ± 6º (Komi & Mero, 1985) and U.S. athletes, describing an angle of 1 ± 5º (Whiting et al., 1991). The highest value of attack angle was presented by Bennett et al. (2017a) evaluating the finalists of the London 2017 Athletics World Championships, where the average value attained was 5.19 ± 3.65º. According to the results presented in this review, women competitors present higher values of attack angle than man. Therefore, at the 1992 Olympic Games at Barcelona, the women finalists attained an attack angle of 6 ± 7º (Mero et al., 1994), similar to those described at the London's 2017 Athletics World Championships of 6.08 ± 6.05º (Bennett et al., 2017b) and to those presented by Viitasalo et al. (2003) of 6.6 ± 6.9º. According to Panoutsakopoulos and Kollias (2013) study, the top female throwers analysed presented an attack angle of 5 ± 6.7º which is slightly higher than the values presented one year early by Jung et al. (2012) of 3.7 ± 1.1º. The lower values are presented by Aleksić-Veljković et al. (2012) and Komi and Mero (1985) with attack angles of 0.9 ± 0.88º and -4 ± 6º, respectively. A study led by Morriss et al. (1997) aimed to find a pattern in several parameters, including the attack angle, between different skill levels. However, the relation between the attack angle and the distance thrown was inconclusive. Several more studies calculated a correlation between these two parameters and all of them presented an insignificant correlation between the attack angle and the distance of the throw (Hussain & Bari, 2012; Ito et al., 2006; Panoutsakopoulos & Kollias, 2013; Viitasalo et al., 2003). The highest correlation was presented by Kunz and Kaufmann (1983) of -0.604, but still, not significant. Summarizing, non-elite male athletes presented values of 2.1º, elite male demonstrated an average of 2.06 ± 2.05º; non-elite female athletes presented 0.9º and elite female competitors evidenced an average attack angle of 3.89 ± 4º (see Table 3).

1.4.4.4. Sideslip

Another relevant parameter frequently discussed on javelin throwing is the sideslip, also known by angle of yaw. This angle is defined by the difference between the lateral movement of the upper body and the arm and the position of the implement's long axis (Bartonietz, 2000) and it's positive in counter-clockwise when observed from above (Bartlett et al., 1996). In other words, seen from behind, it is the angle between the release velocity vector and the javelin's longitudinal axis (Best et al., 1993). It is suggested that athletes normally achieve their best results with smaller yaw angles (Bartonietz, 2000). However, the advisability of a zero sideslip is not clear (Bartlett et al., 1996). Values of yaw angle at release different from zero generate drag forces that retard the javelin (Bartlett et al., 1996). Consequently, the lack of control regarding this angle is more noticeable for novice athletes (Bartlett et al., 1996). However, according to Best et al. (1993), a negative angle of yaw at release produces a positive magnus lift force leading to a spin throughout the long axis of the implement. Accordingly, the authors believe that this positive effect might overcome the undesirable effect of the increased drag, therefore, an optimal release yaw angle is a small negative value. The results among the literature are difficult to analyze because each investigator has his own way of declaring the angles specially when it comes to positive and negative values. Some authors consider different ways of measuring the angle according to their throwing hand which makes total sense. For example, Bennett et al. (2017a, 2017b) specifically mentioned in their reports that, according to the athletes throwing hand, they adapted their analyzes by trading the direction of negative and positive if the athletes were left handed. In other words, in the athlete was right handed a negative slideslip would indicate a sideslip to the left whereas a positive angle would indicate a sideslip to the right. Oppositely, if the athlete was left-handed a negative slideslip would indicate a sideslip to the right and vice-versa. Thus, this study reported a sideslip of 14 ± 4.24 º in male and 8.89 ± 9.07 º in female competitors at the IAAF's 2017 World Championships (Bennett et al., 2017b, 2017a). Similar results are presented by Lehmann (2010) at the 2009 IAAF's World Championships where the first four places achieved an average yaw of 12.5º and, from the 4th until the 11th place, athletes attained 14.1º. As it happened in the studies by Bennett et al. (2017), Lehmann (2010) female athletes presented a smaller angle than the men (10.8 º). At the World Championships of 1995, the male finalists reported a yaw of 7± 4,47 º (Morriss et al., 1997). The only published article that compares different levels of athletes reported that elite competitors attained -3.27 ± 3.07º, club level athletes evidenced an angle of -2.33 ± 2.53º and novice of -9.64 ± 4.9º (Bartlett et al., 1996). In this study, the novice demonstrated a substantial lower value than the club level athletes which led to a significant statistical difference of $p<0.01$. No significant differences between the elite and the other two groups was found, however, the mean value for the elite group it's considerably closer to the club group than the novices. Finally, Bartlett et al. (1996) suggested that there is an important role of the three-dimensional filming to play on the analyses of this angle since this parameter can't be measured from a side-on camera. Finally, the results summary showed that non-elite male athletes presented values of -5.99 ± 5.17 º, elite male demonstrated an average of 8.87 ± 7.38 º and elite female competitors evidenced an average release angle of 9.85 ± 1.35 º (see Table 3).

1.5. Limitations

This review has some limitations. Only English language publications were considered which possibly decreases the number of included of studies. Some studies written in German and Chinese were found but this condition has become the interpretation and reading impossible. The choice of including the official IAAF reports can also be considered a limitation since they haven´t been published on a peer-published journal. However, despite this disadvantage, they were found to be relevant to include on the systematic review.

1.6. Conclusions and Implications

Based on this systematic review, almost all the studies on javelin throwing use the video recording to analyse its motion parameters. Optimal values of the parameters should be taken into account during training sessions to improve athletes' skills and thus performance (Bartonietz, 2000). These optimal values are guidelines to drive coaches to choose the best training methods, however, training sessions should be adapted to every individuality, respecting the holistic view of the athlete. Several parameters do not describe a linear efficiency tendency and show that different techniques end out to be similarly effective. According to literature, 3D analysis method allows investigators to analyze parameters which cannot be observed with 2D (Bartlett et al., 1996). Therefore, they recognize that the 3D analysis method ensures a more detailed evaluation of technique when compared with 2D (Best et al., 1993). However, both methods are found to be slow providing feedback. That is why a new trend has started to rise around athletics community to monitor performance in real-time. Portable and wearable sport devices integrating sensor technology (IMU) have shown its usefulness by providing immediate feedback on workloads and movement technique (Li et al., 2016). Break throughs on IMU devices have endorsed individual athletes, team sports, and physicians to monitor sportsman motion (Loader et al., 2012), workload (Mooney et al., 2011; Varley et al., 2012) and biomarkers (Foster et al., 2010) attempting to improve performance and prevent injury. There are no scientific studies using IMU sensors aiming the javelin's throw performance analysis. Therefore, there is a need to apply new technologies on the sport in order to enhance the athletes'/coach's perception of performance, having always in mind the quality of the provided information.

Chapter 2

The importance of the IMU devices as a complementary information to cinematic analysis on javelin throw

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The importance of the IMU devices as a complementary information to kinematic analysis on javelin throw

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Abstract

In the past few years, wearable technologies for monitoring human movement have become undoubtedly popular. A trend has started to rise around athletics environment to monitor performance during real-time activities. Lately, Inertial Measurement Unit (IMU) based sensors have emerged to quantify human movement. The present study aims to understand the importance of using IMU devices as a tool to evaluate javelin's throw kinematics at training contexts. **Participants:** 5 Portuguese athletes, 2 young male (age: 18±1.41 years; height: 179±8.49 cm; weight: 82±14.14 kg) and 3 young female (age: 18.67±2.08 years; height: 172±83.61 cm; weight: 74.33±4.04 kg). **Instruments:** 2 IMU sensors (Vmax Pro Science, VmaxPro, Magdeburg, Germany); 3 high-speed video cameras. **Data and statistical analysis:** Kinovea® (version 0.8.15) for video analysis with a mathematical analysis software to convert the digital coordinates in real coordinates through the 3D DLT method. JAMOVI (version 1.1.9) was applied for statistical analysis. **Results:** VIDy_hip= 0.778; VIDz_hip= 0.925; VIDv_hio=0.905; IMUx_hip=0.666; IMUa_hip=0.803; VIDy_jav=0.623; IMUa_jav=0.598. Conclusions: The IMU devices, in javelin throw kinematics assessment, are considered highly pertinent and applicable since its outcomes are accurate and effortless.Plus, these sensors enhance fast feedback to coaches and athletes by quickly providing them the kinematic motion analysis.

Key-words: inertial measurement unit, wearable devices, javelin throw, sports performance, kinematic analysis

2.1. Introduction

The Biomechanical understanding about a particular sporting discipline supports the improvement of the internal awareness that each athlete has about his body. By another words, athletes that benefit from a biomechanical acquaintance about itself on the sport can develop a better sensory feedback. Despite of the distance thrown being the final performance outcome, pertinent biomechanical data provides a detailed performance diagnosis, useful to improve technical aspects. Consequently, the knowledge about the movement organization comes from observing throws and measuring performance throughout distinct kinds of equipment (Bartonietz, 2000).

Recently, sports sciences have concentrated on optimizing the javelin's throwing technique as well as the training methods (Särkkä et al., 2016). Since the javelin throw implies a great movement speed at the ejection phase, the feedback from the athlete's own perception of its movement becomes very difficult to perceive (Särkkä et al., 2016). The high speed of the thrower's movement at release causes great problems for athletes, coaches and researchers to understand and have/provide feedback about the thrower's action performance. Usually, the athlete receives feedback about the quality of the projectile motion solely on the distance thrown. Nevertheless, the javelin throwing it's a technically tough discipline which induces large loads on the body segments and requires an high coordination ability as well as great power (Särkkä et al., 2016).

Curiosity on javelin's technique complexity led to implement modern analysis methods in order to offer to the coach and athlete a more flexible way to view the throw (Best et al., 1993). The studies on javelin's throw kinematics are essentially based on video or film recordings and two or three-dimensional motion analysis which is recommended by Bartlett & Best (1988) as the best method to improve technique's feedback since it enhances a far more detailed evaluation on technique (Best et al., 1993). The release variables have been observed and determined predominantly using high-speed filming/video cameras and motion analysis. However, these are slow methods providing feedback for athletes and coaches (Viitasalo et al., 2003). According to Hubbard & Alaways (1989), information must be available to the athlete within a relatively brief period of time so that succeeding throws or drills in a training session can be adjusted grounded on the information obtained from the previous ones. Education sciences assume that immediate feedback is always a valid way to improve skill (Shea & Wulf, 1999). Thus, it's also presumed that technologies that provide immediate feedback are beneficial for learning. This might justified by the fact that self-information and personal perceptions of the movements are permanently consciously paralleled with the objective information from an outside source (Hassan, 2015). According to Hassan (2015), a method to measure velocity that does not compromises the performance is needed, targeting the use in learning/training contexts. Each trial result must be available almost instantaneously and the information should be easy to understand and interpret. For the above reason, new performance analysis instruments are rising to provide to athletes and coaches an immediate and customized feedback. There's an emergent concern in developing human motion capture technologies which ca be used outside the clinic or laboratory environment, by enabling the measurements for monitoring or evaluation at home, work, hospitals, gyms, sport fields, etc (Strohrmann, Harms, Tröster, Hensler, & Müller, 2011; Tarnita, 2016). Advances in sensing technology are emerging by the shape of miniature sensors enabling body worn recognizing and human motion analysis (Sabatini, Martelloni, Scapellato, & Cavallo, 2005). An example of modern and low-cost technology which are gaining space on the performance analysis sciences and also on the athletics throwing events' analysis are the inertial measurement unit (IMU) devices (Särkkä et al., 2016). In past few years, the inertial sensors suffered an exponential progress, especially because of its potential when compared with traditional monitoring systems, such as video-based systems. An auspicious frontier for wearable and reliable motion capture systems is based on inertial measurement units (IMUs) which are comfortable and portable devices that can be used anywhere (Silva, 2014). A trend has started to rise around athletics environment to monitor performance during real-time activities. Portable and wearable sports devices integrating sensor technology have profited from increased commercial exposure as an effective tool to assess physical activity. Athletes set a growing role for the use of wearable sensor technology since it enhances immediate feedback on workloads and technique (Li et al., 2016).

Developments on these equipment have permitted individual athletes, team sports, physicians to monitor sportsman motion (Loader et al., 2012), workload (Mooney et al., 2011; Varley et al., 2012) and biomarkers (Foster et al., 2010) in attempts to enhance performance and avoid injury. Devices, such as accelerometers, turn out to be an attractive instrument for detection and measurement of human motion (Knight et al., 2007). The sensors can be used to record specific aspects of technique when performing a particular action. A previous study analysed biaxial accelerometery curves by placing accelerometers on subjects' chest and wrist while performing shot put, javelin and discus throw. Through this devices, investigators believe that accelerometers can provide information regarding athlete's technique which might be useful for coaches (Knight et al., 2007). Previous studies report the use of accelerometers in sport performance, namely in Olympic lifts where the devices are placed on the barbells (Sato, Smith, & Sands, 2009). Lately, the IMU sensors have emerged to quantify human movement. IMU used in a biomechanical context are either build on accelerometers alone, a grouping with gyroscopes or a combination with both gyroscopes and magnetometers (Wirth et al., 2019). Hence, the combination of sensors has strong benefits since each of these singular electromechanical sensors compensate each other's limitation (Schall, Fethke, Chen, Oyama, & Douphrate, 2016). For example, accelerometers only offer information on inclination, however, it doesn't recognize the orientation of the IMU. Therefore, to cover this flaw, gyroscopes are integrated, nevertheless they might suffer from drift, which can be reduced by a magnetometers (Luinge, Veltink, & Baten, 2007). A device with such a versatile capacity has the ability to confront constraints like space, lightness and autonomy inflicted by the measurement of human activities (Boyd, Ball, & Aughey, 2011; Lee, Sutter, Askew, & Burkett, 2010; Patterson, Mcgrath, & Caulfield, 2011). These devices have suffered numerous technological improvements and become increasingly more accurate (Boddy et al., 2019). The IMU sensors have been validated for biomechanical analysis in areas like gait analysis (Kavanagh & Menz, 2008), swimming biomechanics (Magalhaes, Vannozzi, Gatta, & Fantozzi, 2015) and running kinematics (Provot, Chiementin, Oudin, Bolaers, & Murer, 2017). Also, in cricket these sensors are gaining more and more popularity aiming the kinematic analysis of throwers. One study located wearable IMU devices on the athletes arms and measured the kinematic positions to qualify whether the cricket bowls were legal or not (Wixted, James, & Portus, 2011). Another study analysed peak outward acceleration of cricket bowlers using inertial sensors (Spratford, Portus, Wixted, Leadbetter, & James, 2015). However, studies aiming the IMU validation are limited in the scientific scope (Boddy et al., 2019). Moreover, in baseball, a study reported that IMU sensors were attached in pitchers pelvis and torso to evaluate rotation and on the wrist to identify the timing of the throwing motion's acceleration phase (Grimpampi, Masci, Pesce, & Vannozzi, 2016).

A study conducted by Särkkä et al. (2016), saw these benefits and carried out an investigation where scientists implanted an IMU device on a javelin's tip to determine javelin's momentary attitude, position and velocity. Afterwards, to estimate the accuracy of inertial measurements, the acceleration phase results were compared to the measurements collected with high-speed cameras. They concluded that the IMU enlarged with data acquired from video analysis can be effectively useful to estimate the attitude, position and velocity of the javelin from the run-up to the instant of landing. There's a lack of studies and information provided by the use of IMU system devices in javelin throw. Are these devices useful for athletes and coaches by providing a fast feedback? Are they accurate and related with the result? What are the advantages and disadvantages of using IMU's on training and competition context? Thus, the present study aims to apply the IMU devices and relate the acceleration results with the performance obtained by the athletes at the training context.

2.2. Methodology

2.2.1. Participants

The study sample included 5 Portuguese athletes, 2 young male (age: 18±1.41years; height: 179±8.49cm; weight: 82±14.14kg) and 3 young female (age: 18.67±2.08years; height: 172±83.61cm; weight: 74.33±4.04kg). All the athletes were training regularly with no injuries for at least 2 months. Three of the included participants were integrated on the Portuguese Federation High Performance Program while the other two were considered regular level athletes.

2.2.2. Data collection

2.2.2.1. Instruments

Two 3-axis IMU devices (Vmax Pro Science, VmaxPro, Magdeburg, Germany) were used to measure acceleration. The Vmax Pro weights 30 g and is 3.8 cm in width, 8 cm in length, and 4 cm in depth (Figure 2). The sensors were connected wirelessly by Bluetooth to an 6th generation Ipad 120 GB (Apple SI) which has a patented Vmax Pro App that processes data coming from two synchronized sensors. A sampling rate of 60 Hz is used for data collection.

Three high-speed video cameras - Panasonic Lumix FZ200 (100Hz) - were used to carry out a 3D kinematic analysis to obtain velocity of body segments and the implement. The global coordinate system followed the International Society of Biomechanics recommendations to standardize the joint coordinate system and the definition of anatomical landmarks to report the kinematic data. Accordingly, x defines the antero-posterior displacement or throw motion direction, y the vertical/proximo-distal direction and z represents the medio-lateral direction. Thus, while describing the coordinate system, the directional signs of the forces should also be described to provide an additional information to the reader (Derrick et al., 2020; Wu et al., 2002).

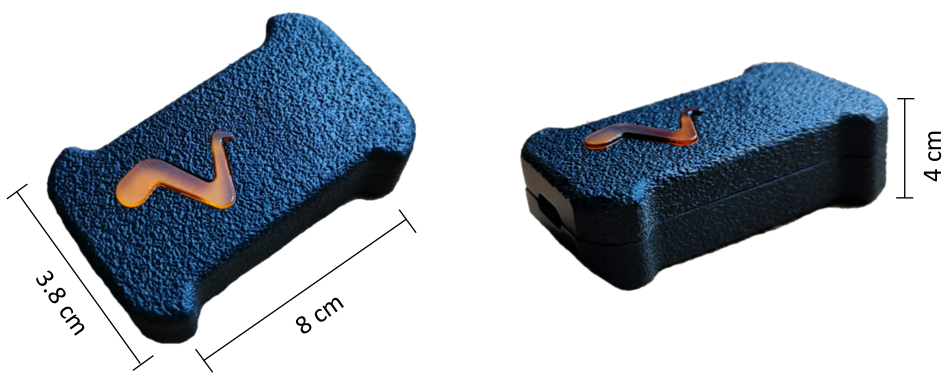

Figure 2 - *IMU device Vmax Pro by Blaumann & Meyer - Sports*

2.2.2.2. Procedures

The first step stands on the set-up of the cameras and its calibration. Three high-definition video cameras recorded the complete (run-up, crossovers, delivery and recovery phase) javelin attempt. One of the cameras was placed at the right side of the runway, while another one at the left and, the third one on the back (Figure 3). The angle between optical axes of both camcorders will describe an angle of 90°. The calibration will be established with a calibration volume (height: 2.8m) placed on the markers and recorded by the cameras prior to data collection. Ten global reference markers will be placed at known positions on the ground so that a global reference frame could be recognized in data reduction (Figure 3). The x-axis will point forward to the throwing area (frontal plane), the z-axis will point to the right side of the runway (sagittal plane), and the y-axis will point upwards (horizontal plane) (Figure 3).

Afterwards, the two devices were calibrated according to the app procedures and securely attached with elastics suitable straps to each athletes' intended body segments. One sensor was placed on the throwing wrist, and another one on the hip side which corresponds with the throwing arm.

No standardized warm-up was applied hence each athlete performed its own preparation in order to respect their own personal routines. Random attempts were recorded, and distance threw measured.

The data collection occurred during one training session on the Portuguese Centre of High Performance (Lisbon, Portugal). Each integrant participant signed a consent declaration and answered to some related questions voluntarily. The data collection was also consented by coaches and the Portuguese Athletic Federation members.

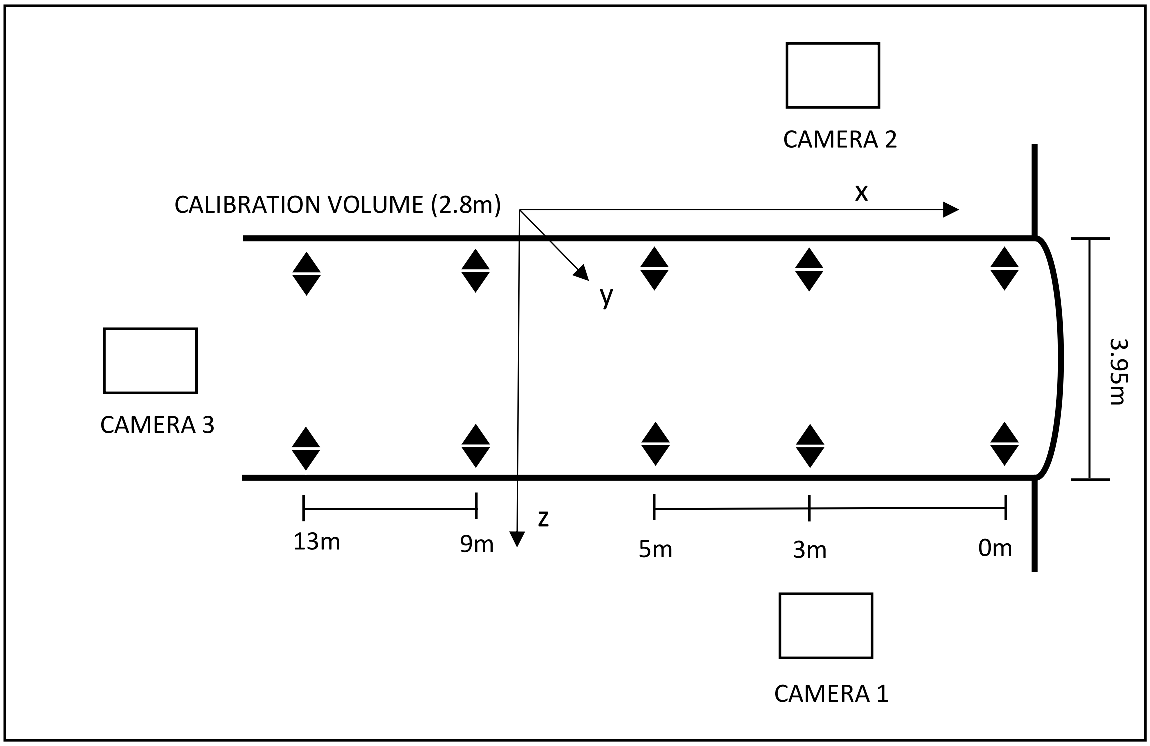

Figure 3 *- Cameras and calibration set-up for data collection*

2.2.3. Data reduction and analysis

The videos were analysed with Kinovea® (version 0.8.15) where, after calibration, key segments (javelin's grip and hip) were manually tracked to obtain the 2D coordinates data from the videoclips. Data smoothing was also performed at a cut frequency of 20 Hz. Afterwards, exported information was converted into 3D through the Direct Linear Transformation (DLT) method (https://isbweb.org/). The database was organized with Excel Microsoft Office (version 16.22). The IMU data was extracted directly from the app software and an interpolation was performed to stabilize the collection frequency at 63 Hz.

2.2.4. Statistical analysis

To check normality, Shapiro-Wilk test was performed, and both normal and non-normal distribution were observed. Therefore, Pearson's and Spearman correlation coefficients were applied in normal and non-normal distributed variables, accordingly, in order to analyse the strength of the relationship between IMU and video results and outcomes (thrown distance). The correlation strength is quantified with a number which varies between -1 and 1, where 0 means that there's no correlation and -1/1 means a complete or perfect correlation. The relation magnitude will be interpreted as weak (0.1-0.3), moderate (0.4-0.6) and strong (0.7-0.9) (Akoglu, 2018). All the calculations were performed on JAMOVI software (1.1.9).

2.3. Results

The descriptive statistics table (Table 4) of the studied variables shows each parameter mean and standard deviation according to the overall video data and IMU results. The result parameter of the overall distance thrown was 49.68±12.41m. Regarding the video hip velocity, according to the antero-posterior direction (VIDx_hip), the sample presented 0.96±0.61m/s; the proximo-distal (VIDy_hip) direction described 1.51±0.39m/s; the medio-lateral (VIDz_hip) showed 5.85±0.76m/s; and, finally, the resultant vector presented a mean value of 6.14±0.85m/s. The same body segment analyzed by the IMU described an antero-posterior acceleration direction (IMUx_hip) of 4.84±3.33m/s^2; the proximo-distal (IMUy_hip) direction was 2.39±2.22m/s^2; the medio-lateral acceleration (IMUz_hip) described 4.95±4.25m/s^2; and, finally, the IMU acceleration resultant (IMUa_hip) described 8.26±4.25m/s^2. Regarding the javelin velocity results, the antero-posterior direction described a velocity of 19.52±4.63m/s (VIDx_jav); the proximo-distal (VIDy_jav) demonstrated 10.75±2.11m/s; the medio-lateral (VIDz_jav) showed 3.57±2.45m/s; and, lastly, the resultant vector (VIDv_jav) described 15.61±4.59m/s. Finally, the javelin IMU overall results showed an acceleration of 31.25±2.91m/s^2 according to the antero-posterior direction (IMUx_jav), 20.32±17.40m/s^2 on the proximo-distal (IMUy_jav), 24.66±8.97m/s^2 according to medio-lateral (IMUz_jav). The javelin's resultant acceleration (IMUa_jav) was 48.47±2.19m/s^2.

***Table 4** - Descriptive statistics of the studied variables*

Variable	**VID (M±SD)**	**IMU (M±SD)**
Result (m)	49.68±12.41	49.68±12.41
VIDx_hip (m/s)	0.96±0.61	
VIDy_hip (m/s)	1.51±0.39	
VIDz_hip (m/s)	5.85±0.76	
VID_hip (m/s)	6.14±0.85	
IMUx_hip (m/s2)		4.84±3.33
IMUy_hip (m/s2)		2.39±2.22
IMUz_hip (m/s2)		4.95±4.25
IMU_hip (m/s2)		8.26±4.25
VIDz_jav (m/s)	19.52±4.63	
VIDy_jav (m/s)	10.75±2.11	
VIDx_jav (m/s)	3.57±2.45	
VID_jav (m/s)	15.61±4.59	
IMUx_jav (m/s2)		31.25±2.91*
IMUy_jav (m/s2)		20.32±17.40*
IMUz_jav (m/s2)		24.66±8.97*
IMU_jav (m/s2)		48.47±2.19

*$p \leq 0.05$ - non-normal distributed

The following table (Table 5) displays each athletes' trial extracted from the video analysis. Thus, on this table are presented each trial result, maximum hip velocity according to the 3 directions and its velocity resultant. The first athlete (A), on his first trial, presented a distance thrown of 62.70m, a video hip's maximum antero-posterior velocity (VIDx_hip) of 0.55m/s, a hip's maximum proximo-distal velocity (VIDy_hip) of 1.79m/s, a hip's maximum medio-lateral velocity (VIDz_hip) of 0.55m/s and, finally, a resultant velocity (VIDv_hip) of 7.03m/s. The second trial described a result of 68.15m, a VIDx_hip of 0.94m/s, a VIDy_hip of 1.84m/s, a VIDz_hip of 6.60m/s and a resultant hip velocity (VIDv_hip) of 6.92m/s. At the last trial, the athlete threw 70.37m with a VIDx_hip of 1.88m/s, a VIDy_hip of 2.10m/s, a VIDz_hip of 7.27m/s and a resultant of

7.80m/s. The athlete B, on his single trial, presented a distance thrown of 54.02m, a video hip's maximum antero-posterior velocity (VIDx_hip) of 0.56m/s, a hip's maximum proximo-distal velocity (VIDy_hip) of 2.06m/s, a hip's maximum medio-lateral velocity (VIDz_hip) of 6.32m/s and, finally, a resultant velocity (VIDv_hip) of 6.67m/s. The athlete C, on her first trial, presented a distance thrown of 44.34m, a video hip's maximum antero-posterior velocity (VIDx_hip) of 1.94m/s, a hip's maximum proximo-distal velocity (VIDy_hip) of 1.45m/s, a hip's maximum medio-lateral velocity (VIDz_hip) of 5.67m/s and, finally, a resultant velocity (VIDv_hip) of 6.17m/s. The second trial described a result of 47.24m, a VIDx_hip of 1.48m/s, a VIDy_hip of 1.21m/s, a VIDz_hip of 5.56m/s and a resultant hip velocity (VIDv_hip) of 5.88m/s. At the last trial, the athlete threw 47.50m with a VIDx_hip of 0.38m/s, a VIDy_hip of 1.06m/s, a VIDz_hip of 5.05m/s and a resultant (VIDv_hip) of 5.17m/s. The athlete D, on her single trial, presented a distance thrown of 37.60m, a video hip's maximum antero-posterior velocity (VIDx_hip) of 0.26m/s, a hip's maximum proximo-distal velocity (VIDy_hip) of 1.04m/s, a hip's maximum medio-lateral velocity (VIDz_hip) of 5.44m/s and, finally, a resultant velocity (VIDv_hip) of 5.55m/s. The athlete E, on her first trial, presented a distance thrown of 37.47m, a video hip's maximum antero-posterior velocity (VIDx_hip) of 1.42m/s, a hip's maximum proximo-distal velocity (VIDy_hip) of 1.34m/s, a hip's maximum medio-lateral velocity (VIDz_hip) of 5.32m/s and, finally, a resultant velocity (VIDv_hip) of 5.67m/s. The second trial described a result of 38.20m, a VIDx_hip of 0.55m/s, a VIDy_hip of 1.14m/s, a VIDz_hip of 5.19m/s and a resultant hip velocity (VIDv_hip) of 5.34m/s. At the last trial, the athlete threw 38.87m with a VIDx_hip of 0.64m/s, a VIDy_hip of 1.57m/s, a VIDz_hip of 5.13m/s and a resultant (VIDv_hip) of 5.40m/s.

Table 5 *- Hip video results of the maximum velocity vectors and velocity resultant*

Subject	Gender, f/m	Trial, nº	Result, m	VIDx_hip, m/s	VIDy_hip, m/s	VIDz_hip, m/s	VIDv_hip, m/s
A	m	1	62.70	0.55	1.79	6.78	7.03
		2	68.15	0.94	1.84	6.60	6.92
		3	70.37	1.88	2.10	7.27	7.80

B	m	1	54.02	0.56	2.06	6.32	6.67
C	f	1	44.34	1.94	1.45	5.67	6.17
		2	47.24	1.48	1.21	5.56	5.88
		3	47.50	0.38	1.06	5.05	5.17
D	f	1	37.60	0.26	1.04	5.44	5.55
E	f	1	37.47	1.42	1.34	5.32	5.67
		2	38.20	0.55	1.14	5.19	5.34
		3	38.87	0.64	1.57	5.13	5.40

*f – female; m – male; m/s – meters per second

The following table (Table 6) shows each athletes' trial extracted from the IMU analysis. Hence, on this table are presented each trial result, maximum hip acceleration according to the 3 directions and its acceleration resultant. The first athlete (A), on his first trial, presented a IMU hip's maximum antero-posterior acceleration (IMUx_hip) of 9.52m/s^2, a hip's maximum proximo-distal acceleration (IMUy_hip) of 1.85m/s^2, a hip's maximum medio-lateral acceleration (IMUz_hip) of 0.48m/s^2 and, finally, a resultant acceleration (IMUa_hip) of 9.71m/s^2. The second trial described an IMUx_hip of 5.64m/s^2, an IMUy_hip of 0.36m/s^2, an IMUz_hip of -12.23m/s^2 and a resultant hip acceleration (IMUa_hip) of 13.47m/s^2. At the last trial, he presented an IMUx_hip of 11.51m/s^2, an IMUy_hip of 5.04m/s^2, an IMUz_hip of -11.22m/s^2 and a resultant of 16.85m/s^2. The athlete B, on his single trial, presented an IMU hip's maximum antero-posterior acceleration (IMUx_hip) of 1.02m/s^2, a hip's maximum proximo-distal acceleration (IMUy_hip) of 1.86m/s^2, a hip's maximum medio-lateral acceleration (IMUz_hip) of -5.65m/s^2 and, finally, a resultant acceleration (IMUa_hip) of 6.03m/s^2. The athlete C, on her first trial, presented a IMU hip's maximum antero-posterior acceleration (IMUx_hip) of 5.34m/s^2, a hip's maximum proximo-distal acceleration (IMUy_hip) of 0.52m/s^2, a hip's maximum medio-lateral acceleration (IMUz_hip) of -0.93m/s^2 and, finally, a resultant acceleration (IMUa_hip) of 5.44m/s^2. The second trial described an IMUx_hip of 5.54m/s^2, an IMUy_hip of

6.88m/s^2, an IMUz_hip of 5.97m/s^2 and a resultant hip acceleration (IMUa_hip) of 10.66m/s^2. At the last trial, she presented an IMUx_hip of 1.85m/s^2, an IMUy_hip of 4.16m/s^2, an IMUz_hip of 3.99m/s^2 and a resultant of 6.06m/s^2. The athlete D, on her single trial, presented an IMU hip's maximum antero-posterior acceleration (IMUx_hip) of 2.26m/s^2, a hip's maximum proximo-distal acceleration (IMUy_hip) of 0.28m/s^2, a hip's maximum medio-lateral acceleration (IMUz_hip) of -0.32m/s^2 and, finally, a resultant acceleration (IMUa_hip) of 2.30m/s^2. The athlete E, on her first trial, presented a IMU hip's maximum antero-posterior acceleration (IMUx_hip) of 2.70m/s^2, a hip's maximum proximo-distal acceleration (IMUy_hip) of 2.07m/s^2, a hip's maximum medio-lateral acceleration (IMUz_hip) of 2.45m/s^2 and, finally, a resultant acceleration (IMUa_hip) of 4.19m/s^2. The second trial described an IMUx_hip of 3.27m/s^2, an IMUy_hip of 2.33m/s^2, an IMUz_hip of 5.78m/s^2 and a resultant hip acceleration (IMUa_hip) of 7.04m/s^2. At the last trial, she presented an IMUx_hip of 0.07m/s^2, an IMUy_hip of 8.86m/s^2, an IMUz_hip of 2.07m/s^2 and a resultant of 9.10m/s^2.

Table 6 *- Hip IMU results of the maximum acceleration vectors and resultant acceleration*

Subject	Gender, f/m	Trial, nº	Result, m	IMUx_hip, m/s^2	IMUy_hip, m/s^2	IMUz_hip, m/s^2	IMUa_hip, m/s^2
A	m	1	62.70	9.52	1.85	0.48	9.71
		2	68.15	5.64	0.36	-12.23	13.47
		3	70.37	11.51	5.04	-11.22	16.85
B	m	1	54.02	1.02	1.86	-5.65	6.03
C	f	1	44.34	5.34	0.52	-0.93	5.44
		2	47.24	5.54	6.88	5.97	10.66
		3	47.50	1.85	4.16	3.99	6.06
D	f	1	37.60	2.26	0.28	-0.32	2.30
E	f	1	37.47	2.70	2.07	2.45	4.19

	2	38.20	3.27	2.33	5.78	7.04
	3	38.87	0.07	8.86	2.07	9.10

*f – female; m – male; m/s – meters per second squared

The table 7 presents the video analysis on the maximum javelin's velocity according to the 3 directions and its resultant velocity. The athlete A, on his first trial, presented a video javelin's maximum antero-posterior velocity (VIDx_jav) of 2.65m/s, a javelin's maximum proximo-distal velocity (VIDy_jav) of 12.30m/s, a javelin's maximum medio-lateral velocity (VIDz_jav) of 14.79m/s and, lastly, a resultant velocity (VIDv_jav) of 19.42m/s. The second trial described a VIDx_jav of 2.92m/s, a VIDy_jav of 14.26m/s, a VIDz_jav of 16.99m/s and a resultant javelin velocity (VIDv_jav) of 22.37m/s. At the last trial, the athlete described a VIDx_jav of 6.93m/s, a VIDy_jav of 11.72m/s, a VIDz_jav of 20.44m/s and a resultant of 24.56m/s. The athlete B, on his single trial, presented a video javelin's maximum antero-posterior velocity (VIDx_jav) of 2.75m/s, a javelin's maximum proximo-distal velocity (VIDy_jav) of 12.35m/s, a javelin's maximum medio-lateral velocity (VIDz_jav) of 21.06m/s and, finally, a resultant velocity (VIDv_jav) of 24.57m/s. The athlete C, on her first trial, presented a video javelin's maximum antero-posterior velocity (VIDx_jav) of 7.56m/s, a javelin's maximum proximo-distal velocity (VIDy_jav) of 10.58m/s, a javelin's maximum medio-lateral velocity (VIDz_jav) of 18.48m/s and, lastly, a resultant velocity (VIDv_jav) of 22.60m/s. The second trial described a VIDx_jav of 6.84m/s, a VIDy_jav of 9.71m/s, a VIDz_jav of 21.25m/s and a resultant javelin velocity (VIDv_jav) of 24.34m/s. At the last trial, the athlete described a VIDx_jav of 0.06m/s, a VIDy_jav of 7.68m/s, a VIDz_jav of 10.82m/s and a resultant of 13.27m/s. The athlete D, on her single trial, presented a video javelin's maximum antero-posterior velocity (VIDx_jav) of 1.38m/s, a javelin's maximum proximo-distal velocity (VIDy_jav) of 6.99m/s, a javelin's maximum medio-lateral velocity (VIDz_jav) of 9.75m/s and, finally, a resultant velocity (VIDv_jav) of 12.08m/s. The athlete E, on her first trial, presented a video javelin's maximum antero-posterior velocity (VIDx_jav) of 2.90m/s, a javelin's maximum proximo-distal velocity (VIDy_jav) of 10.74m/s, a javelin's maximum medio-lateral velocity (VIDz_jav) of 15.59m/s and, lastly, a resultant velocity (VIDv_jav) of 19.15m/s. The second trial described a VIDx_jav of 3.18m/s, a VIDy_jav of 10.06m/s, a VIDz_jav of 14.45m/s and a resultant javelin velocity (VIDv_jav) of 17.89m/s. At the final trial, the athlete described a VIDx_jav of 2.05m/s, a VIDy_jav of 11.89m/s, a VIDz_jav of 8.09m/s and a resultant of 14.53m/s.

Table 7 - *Javelin video results of the release velocity vectors and resultant velocity*

Subject	Gender, f/m	Trial, nº	Result, m	VIDx_jav, m/s	VIDy_jav, m/s	VIDz_jav, m/s	VIDv_jav, m/s
A	m	1	62.70	2.65	12.30	14.79	19.42
		2	68.15	2.92	14.26	16.99	22.37
		3	70.37	6.93	11.72	20.44	24.56
B	m	1	54.02	2.75	12.35	21.06	24.57
C	f	1	44.34	7.56	10.58	18.48	22.60
		2	47.24	6.84	9.71	21.25	24.34
		3	47.50	0.06	7.68	10.82	13.27
D	f	1	37.60	1.38	6.99	9.75	12.08
E	f	1	37.47	2.90	10.74	15.59	19.15
		2	38.20	3.18	10.06	14.45	17.89
		3	38.87	2.05	11.89	8.09	14.53

*f – female; m – male; m/s – meters per second

The results on the javelin's acceleration (see Table 8) collected from the IMU, are also presented according to the 3 directions and the resultant. The first athlete (A), on his first trial, presented a IMU javelin's maximum antero-posterior acceleration (IMUx_jav) of 32.70m/s^2, a javelin's maximum proximo-distal acceleration (IMUy_jav) of 27.47m/s^2, a javelin's maximum medio-lateral acceleration (IMUz_jav) of 23.13m/s^2 and, finally, a resultant acceleration (IMUa_jav) of 48.57m/s^2. The second trial described an IMUx_jav of 32.70m/s^2, an IMUy_jav of 26.98m/s^2, an IMUz_jav of 23.74m/s^2 and a resultant javelin acceleration (IMUa_jav) of 48.59m/s^2. At the last trial, he presented an IMUx_jav of 32.61m/s^2, an IMUy_jav of 26.44m/s^2, an IMUz_jav of 31.31m/s^2 and a resultant (IMUa_jav) of 52.37m/s^2. The athlete B, on his single trial, presented an IMU javelin's maximum antero-posterior acceleration (IMUx_jav) of 32.76m/s^2, a javelin's maximum proximo-distal acceleration (IMUy_jav) of 24.11m/s^2, a javelin's maximum medio-lateral acceleration (IMUz_jav) of 30.13m/s^2 and, finally, a resultant acceleration (IMUa_jav) of 50.62m/s^2. The athlete C, on her first trial, presented a IMU javelin's maximum antero-posterior acceleration (IMUx_jav) of 31.07m/s^2, a javelin's maximum proximo-distal acceleration (IMUy_jav) of 21.12m/s^2, a javelin's maximum medio-lateral acceleration (IMUz_jav) of 31.66m/s^2 and, finally, a resultant acceleration (IMUa_jav) of 49.13m/s^2. The second trial described an IMUx_jav of 31.98m/s^2, an IMUy_jav of -30.92m/s^2, an IMUz_jav of 7.32m/s^2 and a resultant javelin acceleration (IMUa_jav) of 45.08m/s^2. At the last trial, she presented an IMUx_jav of 32.72m/s^2, an IMUy_jav of 21.82m/s^2, an IMUz_jav of 32.10m/s^2 and a resultant (IMUa_jav) of 50.77m/s^2. The athlete D, on her single trial, presented an IMU javelin's maximum antero-posterior acceleration (IMUx_jav) of 32.68m/s^2, a javelin's maximum proximo-distal acceleration (IMUy_jav) of 29.96m/s^2, a javelin's maximum medio-lateral acceleration (IMUz_jav) of 15.52m/s^2 and, finally, a resultant acceleration (IMUa_jav) of 46.97m/s^2. The athlete E, on her first trial, presented a IMU javelin's maximum antero-posterior acceleration (IMUx_jav) of 23.40m/s^2, a javelin's maximum proximo-distal acceleration (IMUy_jav) of 23.13m/s^2, a javelin's maximum medio-lateral acceleration (IMUz_jav) of 31.86m/s^2 and, lastly, a resultant acceleration (IMUa_jav) of 45.80m/s^2. The second trial described an IMUx_jav of 32.69m/s^2, an IMUy_jav of 32.64m/s^2, an IMUz_jav of 12.86m/s^2 and a resultant javelin acceleration (IMUa_jav) of 47.95m/s^2. At the last trial, she presented an IMUx_jav of 28.43m/s^2, an IMUy_jav of 20.70m/s^2, an IMUz_jav of 31.60m/s^2 and a resultant (IMUa_jav) of 47.28m/s^2.

Table 8 *- Javelin IMU results of the release acceleration vectors and resultant acceleration*

Subject	Gender, f/m	Trial, nº	Result, m	IMUx_jav, m/s^2	IMUy_jav, m/s^2	IMUz_jav, m/s^2	IMUa_jav, m/s^2
A	m	1	62.70	32.70	27.47	23.13	48.57
		2	68.15	32.70	26.98	23.74	48.59
		3	70.37	32.61	26.44	31.31	52.37
B	m	1	54.02	32.76	24.11	30.13	50.62
C	f	1	44.34	31.07	21.12	31.66	49.13
		2	47.24	31.98	-30.92	7.32	45.08
		3	47.50	32.72	21.82	32.10	50.77
D	f	1	37.60	32.68	29.96	15.52	46.97
E	f	1	37.47	23.40	23.13	31.86	45.80
		2	38.20	32.69	32.64	12.86	47.95
		3	38.87	28.43	20.70	31.60	47.28

*f – female; m – male; m/s – meters per second squared

Finally, the last table presents the Pearson's/Spearman's correlation coefficient between the result (distance thrown) and the velocity/acceleration outcomes collected from the video/IMU (see Table 9). Regarding the video hip antero-posterior direction (VIDx_hip), the sample presented a correlation of 0.229 (weak); the proximo-distal (VIDy_hip) direction described a correlation of 0.778 (strong) with statistical significance ($p<0.01$); the medio-lateral (VIDz_hip) described a correlation of 0.925 (strong) also with statistical significance ($p<0.01$); and, finally, the resultant vector presented a correlation of 0.905 (strong) and a significant statistical difference ($p<0.01$). The same body segment analyzed by the IMU described a correlation of 0.666 (moderate) ($p<0.05$) according to the antero-posterior acceleration direction (IMUx_hip); on the proximo-distal (IMUy_hip) direction the correlation was 0.173 (weak); the medio-lateral acceleration (IMUz_hip) described a correlation of 0.577 (moderate); and, finally, the IMU resultant (IMUa_hip) presented a correlation of 0.803 (strong) with a significant statistical difference (p<0.01). Regarding the javelin velocity correlation results, the antero-posterior direction described a correlation of 0.250 (VIDx_jav); the proximo-distal (VIDy_jav) demonstrated a correlation of 0.623 (moderate) with statistical significance (p<0.05); the medio-lateral (VIDz_jav) showed 0.501 (moderate); and, lastly, the resultant vector (VIDv_jav) described a correlation of 0.575 (moderate) with the result. Finally, the javelin IMU overall results showed a correlation of 0.467 (moderate) according to the antero-posterior direction (IMUx_jav), 0.083 (weak) on the proximo-distal (IMUy_jav), 0.176 (weak) according to medio-lateral (IMUz_jav). The javelin's resultant correlation (IMUa_jav) with the result was 0.598 (moderate) (p<0.05).

Table 9 *- Pearson's and Spearman's correlation between the results (distance throw) obtained in training and the velocity results acquired from the video and the acceleration results obtained from the IMU*

Variable	r, correlation	Interpretation
VIDx_hip	0.229	weak
VIDy_hip	**0.778****	strong
VIDz_hip	**0.925****	strong
VIDv_hip	**0.905****	strong
IMUx_hip	**0.666***	moderate
IMUy_hip	0.173	weak
IMUz_hip	0.577	moderate
IMUa_hip	**0.803****	strong
VIDx_jav	0.250	weak
VIDy_jav	**0.623***	moderate
VIDz_jav	0.501	moderate
VIDv_jav	0.575	moderate
IMUx_jav	0.467	moderate
IMUy_jav	0.083	weak
IMUz_jav	0.176	weak
IMUa_jav	**0.598***	moderate

* p <0.05, ** p<0.01 - significative correlation

2.4. Discussion

The present study included distinct skill level athletes as well as both genders. These might support the fact why results are so heterogeneous among variables. According to the results presented on this study, generally, male athletes tend to achieve higher maximum velocity/acceleration values. These outcomes might be grounded on the physic and physiological differences between genders. Sex modifications in body size and composition start to appear at the onset of puberty determined by sex-specific changes in level of hormones production (e.g. as testosterone, estrogen, progesterone, growth hormone) (Sandbakk, Solli, & Holmberg, 2017). Therefore, generally, men describe a larger increase in their absolute and relative muscle mass and present a lower body fat percentage, which leads to a superior muscle strength and power (Sandbakk, Solli, & Holmberg, 2017). According to previous studies applied on elite throwers, male present a greater release velocity (Bartlett et al., 1996; Bennett et al., 2017b, 2017a; Best et al., 1993; Campos et al., 2004, 2002; Jung et al., 2012; Komi & Mero, 1985; Lehmann, 2010; Leigh et al., 2013; Mero et al., 1994; Morriss et al., 1997; Panoutsakopoulos & Kollias, 2013; Viitasalo et al., 2003; Whiting et al., 1991) as well as a greater thrown distance (Bennett et al., 2017a, 2017b; Campos et al., 2004, 2002; Jung et al., 2012; Komi & Mero, 1985; Lehmann, 2010; Mero et al., 1994; Panoutsakopoulos & Kollias, 2013; Whiting et al., 1991) than female elite athletes. Summing up, male subjects have greater muscle strength and a greater power capacity which might lead them to thrower faster and further. The javelin throw and its complex technical and physical demands (Frane et al., 2011) merged to each athlete's individual characteristics, provide space to a wide range throw solutions. That is why, even though athletes present similar thrown distances with similar competition conditions, they present distinct throwing parameters' values, and vice-versa (Bennett et al., 2017a, 2017b; Campos et al., 2004; Jung et al., 2012; Mero et al., 1994). However, when it comes to release velocity, its correlation with distance thrown is highlighted by several authors (Bartlett et al., 1996; Saratlija et al., 2013; Panoutsakopoulos & Kollias, 2013). As mentioned on the previous chapter, release velocity is considered the most important parameter which determines the distance achieved by the implement. This velocity achievement relies on the effectiveness of power transmission from the body to the upper limb and then to the javelin (Campos et al., 2004). Taking a deeper look to the results on this study, the hip proximo-distal velocity direction (VIDy_hip) described a strong correlation (r=0.778, p<0.01) with the performance. Also, the medio-lateral velocity direction (VIDz_hip) revealed the highest values among axis, which indicates that the hip performs a great medio-lateral action and is strongly correlated with the distance thrown (r=0.925, p<0.01). Consequently, the hip resultant velocity expresses a strong correlation (r=0.905, p<0.803) with the distance thrown, confirming the important role played by the hip in javelin throwing. Similar outcomes were presented by the IMU resultant acceleration (IMUa_hip), where the study results demonstrated strong correlation (r=0.803, p<0.01) between this parameter and the distance thrown. Several authors have mentioned the hips crucial role on carrying the kinetic chain during the run-up in order to transmit the stored energy to the throw itself (Frane et al., 2011; Menzel, 1986). Böttcher and Kühl (1998) mentioned the hip optimal position to favor the energy transmission, especially during the delivery stride. They assumed that it is useful to extent the hip and knee during the delivery, however, an over-exaggerated hip extension can be adverse. Hence, to achieve an optimal amortization and extension of the hip, the hip angle should be less than 120º, at the left foot plant moment (Böttcher & Kühl, 1998).

Concerning the implement video analysis, the velocity achieved according to the proximo-distal direction (VIDy_jav) shows a moderate relationship (r=0.623, p<0.05) with the distance thrown, indicating its prominence in the performance. Even though the video results do not express a strong relationship between the javelin release velocity resultant and the distance thrown, previous studies have confirmed that the release velocity is highly correlated with performance (Bartlett et al., 1996; Campos et al., 2002; Panoutsakopoulos & Kollias, 2013; Saratlija et al., 2013; Viitsalo et al., 2013; Hassan, 2015). Accordingly, the javelin's maximum acceleration resultant (IMUa_jav) described a moderate correlation with the distance thrown (r=0.598, p<0.05).

These study results collected with video capturing and IMU highlight the important role that velocity plays on javelin's throw by acknowledging its great impact on performance outcomes. As the javelin is an extremely complex technical athletic discipline, it's believed that IMU sensors are a great alternative to provide relevant and quick information. Especially during training sessions, athletes can benefit from a faster information assessment on technique and, consequently, improve their performance. Future studies should focus on implementing new technologies, such as IMU, by building a bridge between the kinematics outcomes and their practical impact on training methodology.

2.5. Limitations

One of the study limitations relates with the reach of the wireless connectivity between the sensors and the Ipad. The reduced “stretch” of the Bluetooth connection had implications on data collection by interrupting the synch between devices. Additionally, the IMU have to be carefully placed and data posteriorly treated. Collection frequencies describe variance which implies a data interpolation to adjust the values and synchronize with the kinematic data. Consequently, it’s advisable that companies which develop these technologies should carefully modify how data is collected according to its caption frequency. This adjustment would simplify the collected data processing and thus, improve the time and quality of the kinematic report.

2.6. Conclusions and practical application

This study emphasizes the relevance of the velocity on the javelin’s throw performance (distance thrown). The IMU devices, in javelin throw kinematics assessment, are considered highly pertinent and applicable since its outcomes are accurate and effortless. Plus, these sensors enhance fast feedback to coaches and athletes by quickly providing them the kinematic motion analysis. Despite some adjustments on frequency stabilization and wireless connectivity, IMUs can be considered an important tool, if carefully used. Additionally, these technologies, by increasing the training quality, inevitably have positive repercussions on competition’s contexts.

3. References

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Attachments

***Table 10 -** Bias studies quality evalution, n=26*

	Reporting									External validity			Internal validity					
	Hypothesis	Main outcomes	Partici pant charact eristics	Interventions	Findings	Estimates of random variability	Adverse events	Characteristics of participants LTFU	Actual probability values	Representativeness of participants asked	Representativeness of included participants	Representativene ss of testing accomodation	Data dredging	Appropriatene ss of statistics	Compliance with intervention	Outcome measures valid/reliable	Losses of participants taken into account	**TOTAL**
(Aleksić-Veljković et al., 2012)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	1	1	0	**13**
(Bartlett et al., 1996)	1	1	1	1	1	1	0	0	1	1	0	0	1	1	1	1	0	**12**
(Bennett, Walker, Bissas, & Merlino, 2017a)	0	1	1	1	1	0	0	0	0	1	1	0	1	0	1	1	0	**9**
(Bennett, Walker, Bissas, & Merlino, 2017b)	0	1	1	1	1	0	0	0	0	1	1	0	1	0	1	1	0	**9**
(Best et al., 1993)	1	0	1	1	1	0	0	0	0	1	0	0	1	1	1	1	0	**9**
(Campos et al., 2004)	1	1	0	1	1	1	0	0	0	1	1	0	1	1	1	1	0	**11**
(Campos et al., 2002)	1	1	0	1	1	1	0	0	1	0	1	0	1	1	1	1	0	**11**
(Campos et al., 1994)	1	1	0	1	1	0	0	0	1	0	0	0	1	1	1	1	0	**9**
(Hassan, 2015)	1	1	1	1	1	1	0	0	1	1	0	0	1	1	1	1	0	**12**
(Hussain & Bari, 2012)	1	1	1	1	1	1	0	0	1	1	0	0	1	1	1	1	0	**12**
(Jung et al., 2012)	1	1	1	1	1	1	0	0	1	1	0	0	1	1	1	1	0	**12**
(Ito et al., 2006)	1	1	1	1	1	0	0	0	1	1	1	0	1	1	1	1	0	**12**
(Kaur & Deol, 2016)	0	1	1	1	1	1	0	0	1	1	0	0	1	1	1	1	0	**11**
(Komi & Mero, 1985)	1	1	1	1	1	1	0	0	0	1	1	0	1	1	1	1	0	**12**
(Kunz & Kaufmann, 1983)	1	1	1	1	1	0	0	0	1	1	0	0	1	1	1	1	0	**11**
(Lehmann, 2010)	1	0	1	1	1	0	0	0	0	1	1	0	1	1	1	1	0	**10**
(Leigh et al., 2013)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	1	1	0	**13**
(Liu et al., 2010)	1	1	1		1	1	0	0	1	1	1	0	1	1	1	1	0	**12**
(Liu et al., 2014)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	1	1	0	**13**
(Mero et al., 1994)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	1	1	0	**13**
(Morriss, Bartlett, & Fowler, 1997)	0	1	1	1	1	0	0	0	0	1	1	0	1	1	1	1	0	**10**
(Panoutsakopoulos & Kollias, 2013)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	1	1	0	**13**
(Panoutsakopoulos, Vujkov, Kotzamanidou, & Vujkov, 2016)	1	1	1	1	1	1	0	0	1	1	0	0	1	1	1	1	0	**12**
(Saratlija et al., 2013)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	1	1	0	**13**
(Viitasalo et al., 2003)	1	1	1	1	1	1	0	0	1	1	1	0	1	1	1	1	0	**13**
(Whiting, Gregor, & Halushka, 1991)	1	0	1	1	1	1	0	0	1	1	0	0	1	0	1	1	0	**10**
																	Mean=	11,42

DECLARAÇÃO DE CONSENTIMENTO

Eu, ____, portador do CC nº ____________________, declaro que aceito a participar no estudo **"The importance of IMU devices as a kinematic analysis complement in javelin throw"** através da cedência de dados pessoais e direitos de imagem durante os dias 14-20 de abril de 2019 no Jamor (Lisboa).

Foi-me explicado objetivo do estudo, bem como os seus procedimentos.

Por isso, **consinto participar no estudo em causa**:

_____________________________________ Data: __/__/2019

(Assinatura do Participante)