3D KINEMATIC ANALYSIS OF THREE DIFFERENT PUNCHES IN AMATEUR BOXING

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ABSTRACT

3D KINEMATIC ANALYSIS OF THREE DIFFERENT PUNCHES IN AMATEUR BOXING

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The main objective of this study was to determine differences, if any, in three-dimensional (3D) kinematic characteristics of the three principal punches (the jab, hook and uppercut) executed by novice, intermediate and elite level amateur boxers. Specifically, the kinematic variables related to the displacement, linear velocity and acceleration of the upper body segments, translational hand acceleration and vertical ground reaction force generated by boxers were analyzed.

The subjects of this study composed of 10 novice, 9 intermediate, and 11 elite level amateur boxers. Ages of the subjects ranged from 18 to 34 years old. All subjects executed their punches toward a head-high target on a standard practice bag. The motions were captured with PhaseSpace real time optical tracking system with 8 high speed cameras at 240 fps. Then, the motions captured were analyzed to quantify the kinematic factors associated with each punch. The results showed that the uppercut punch generated larger linear shoulder, elbow and wrist velocity compared to the jab

punch. Similarly, the uppercut punch generated larger linear shoulder, elbow and wrist acceleration compared to the hook and jab punches. Moreover, the uppercut and hook punches generated larger translational hand acceleration compared to the jab punch.

As a conclusion, the results for all kinematic variables demonstrated that the type of punch executed was the major determinant of the magnitude of each factor studied. Moreover, the technique employed can significantly affect the resulting displacement, linear velocity and acceleration, and translational hand acceleration of the fist.

Keywords: Boxing, Kinematics, 3D motion analysis

ÖZ

AMATÖR BOKSTA 3 FARKLI YUMRUĞUN 3 BOYUTLU KİNEMATİK ANALİZİ

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Bu çalışmanın esas amacı amatör boksta eğer varsa başlangıç, orta ve elit seviye boksörler tarafından atılan üç temel yumruğun (direk, kroşe ve aparkat) 3 boyutlu kinematik özelliklerini belirlemektir. Özellikle boksörlerin üç farklı yumruğu atarken vücütlarının üst kısımlarındaki uzuvlarının yerdeğiştirmesi, doğrusal hızı ve doğrusal ivmesi, elin doğrusal ivmesi ve dikey yer tepki kuvvetleri gibi kinematik değişkenler analiz edilmiştir.

Bu çalışmanın denekleri 10 başlangıç, 9 orta ve 11 adet de üst düzey amatör boksörlerden oluşmuştur. Deneklerin yaşı 18 ile 34 arasında değişmektedir. Tüm denekler standart bir kum torbası üzerinde baş hizasındaki bir hedefe doğru yumruk atmışlardır. Hareketler 8 adet yüksek hızlı kamera ile saniyede 240 kare fotoğraf çekebilen PhaseSpace gerçek zamanlı optik hareket yakalama sistemi ile kaydedilmiştir. Sonra, kaydedilen hareket bilgileri her bir yumrukla ilgili kinematik değişkenleri sayısallaştırmak için analiz edilmiştir. Sonuçlar aparkatın direk yumruktan daha büyük doğrusal omuz, dirsek ve elbileği hızları oluşturduğunu

göstermiştir. Aynı şekilde, aparkat yumruk, kroşe ve direk yumruktan daha büyük doğrusal omuz, dirsek ve elbileği ivmeleri oluşturmuştur. Ayrıca, aparkat ve kroşe yumruk, direk yumruğa göre daha fazla doğrusal el ivmesi oluşturmuştur.

Sonuç olarak, tüm kinematik değişkenlerin sonuçları ilgilenilen değişkenin büyüklüğünü belirleyen en önemli unsurun atılan yumruğun tipi olduğunu göstermiştir. Ayrıca, uygulanan teknik, yumruktan kaynaklanan yerdeğiştirmeyi, doğrusal hızı, ivmeyi ve doğrusal el ivmesini önemli bir biçimde etkileyebilir.

Anahtar Kelimeler: Boks, Kinematik analiz, Üç boyutlu hareket analizi

To my LOVE and my little daughter

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CHAPTER I

INTRODUCTION

1.1. Background of the Study

Sport of boxing, both professional and amateur, is a growing activity, continually taking in new groups of participants around the world. In many countries men and women are boxing professionally today, and young girls and boys are entertaining spectators by exchanging blows in the ring. Like the other countries, boxing has gained considerable popularity in Turkey nowadays. As a result of increase in popularity, broadcasting of amateur or professional boxing matches on television and the participation rates in group exercise classes, as well as club memberships, have risen. This may be largely due to increasing number of Turkish boxers in the country and abroad and their success at international tournaments and championships. Regardless of the origin, it is apparent that boxing is growing as a sport in Turkey. This upsurge in boxing around the country has also officially registered by International Amateur Boxing Association (AIBA) and announced from their internet site as “a total of 456 boxers competed for glory from 56 cities across Turkey, at the annual Turkish Men's Elite National Championships in the southern part of the country, Mersin, making the event the biggest national championships in Europe in 2010” (AIBA News, 2011).

Boxing actually is one of the contact sports which require multiple skill and technique for guarding, defending and attacking to the opponents (Collins et al., 2010). The main objective in boxing is to impact the opponent while protecting one's self from impacts and the most desirable outcome is to knock out one's opponent, ensuring a win (Mack, Stojsih, Sherman, Dau, & Bir, 2010). Moreover, boxing is a physically and mentally demanding contact sport and boxers are required to possess a combination of endurance, strength, stamina, agility, coordination, and speed (Smith, Dyson, Hale & Janaway 2000; Mack, Stojsih, Sherman, Dau, & Bir, 2010).

Sport of boxing can pretty much be divided into two sections: amateurs and professionals. In both amateur and professional versions, the fighters wear padded gloves, attacking and defending only with fists. Each round generally lasts for three-minutes with a one-minute interval for amateurs and professionals, and the winner is the one who lands the maximum number of clean punches or knocks out his opponent (Sugar, 2007). But, amateur boxing is fundamentally different from professional boxing, including in its motivation to participate, objectives, rules, scoring, equipment and greater emphasis on safety (Hahn et al., 2010). Amateur boxing is also a well-organized and supervised sport where competitors seek to demonstrate courage, skill, intelligence and grace in a contest where they are matched as evenly as possible by age, weight and experience and where a team of officials attends in order to prevent serious injury (Falletta, 1984). Moreover, amateur boxers are required to have headgear, heavily padded gloves to aid in energy absorption, and a sleeveless shirt in the color of their corner, while professionals fight bare-chested and without headgear (AIBA Technical & Competition Rules, 2010).

In amateur boxing, points are scored by landing clean blows, regardless of their power and physical damage. A power punch that knocks an opponent down scores the same as a single jab (AIBA Technical & Competition Rules, 2010). Consequently, a boxer's goal should be to outbox his opponent by landing numerous clean, effective blows rather than going for a knockout that may not happen in amateur boxing. This is intended to encourage finesse boxing, sportsmanship, winning by out pointing the adversary and to discourage knocking down or knocking out the opponent (Kaczmarek, 1996). However, professional boxing is a business and its sole purpose is to make money. Wealth is accumulated from the boxer's sweat and pain (Sammons, 1982). Therefore, professional boxers are encouraged to knock down their opponent, as they are awarded an extra point and often are designated the winner of the round (Werner, 1998). Unlike the amateur boxing, there is considerably greater exposure to injury in professionals due to increased frequency and force of punches over a greater duration of career (McCrory, Zazryn & Cameron, 2007). Most importantly, athlete expose to severe head impacts and the risk of brain injury in professional boxing (Gartland, Malik & Lowell, 2001). Thus, amateur boxing is becoming an increasingly popular participation sport, especially within universities and for both sexes.

Despite its popularity, boxing has always been the source of much debate. Since the nature of boxing involves forceful, repetitive punches, the risk of serious head injuries can be sustained during or after the competition (Unterhamscheidt, 1995; Ross & Ochsner, 1999). Although precautions are implemented to ensure the safety of boxers, head injuries are still a problem (Porter & O'Brien, 1996). Therefore, boxing has come under increased investigation over the past 30 years because of its association with acute and chronic traumatic brain injury (Unterhamscheidt, 1995; Porter & O'Brien, 1996; Ross & Oehsner, 1999). Recent reports have attributed a variety of injuries to participants of boxing including facial lacerations (Zazryn, Finch & McCrory, 2003), eye injuries (Hazar, Beyleroğlu, Subaşı & Or, 2002), hand injuries (Noble, 1987), cardiac and pericardial injuries (Ooi, Douds, Kumar & Nashel, 2003), and acute renal injuries (Unterhamscheidt, 1995). Nevertheless it has inherent dangers, the benefits of the sport outweigh the negative aspects. Boxing provides not only physical, but also psychological benefits (Piau, 1965). Moreover, it develops mental discipline, provides an outlet for aggressive behavior, and helps to overcome feelings of inadequacy and inferiority (Parker & Trifunov, 1960). Therefore, better supervision, reduction in the number of bouts a boxer fights each year, more heavily padded gloves, and other safeguards introduced by boxing authorities can considerably reduce the frequency and severity of injuries (Bledsoe, Li & Levy, 2005; Unterharnscheidt, 1970). Moreover, realizing the possible benefits of boxing, studies concerned the biomechanical assessment of head impact responses are essential if the safety of boxers is wanted to be improved.

It is interesting to note that literature related with biomechanical properties of punches in boxing is limited. We know that the force of a punch is related to the acceleration (a) of the fist and the masses (m) involved (Newtonian F=m.a). It further depends on the mechanical properties of the colliding bodies, namely glove and the target such as head, body or punching bag. On impact, a force is produced in both the gloved fist and target; this force accelerates the target, while the fist decelerated.

During the contact, the two bodies are deformed by this force of impact (Unterharnscheidt & Taylor-Unterharnscheidt, 2003). However, accurate assessment of the striking mass is also a problem, since it is composed of the masses of the glove, hand, forearm, and upper arm, and to a certain degree that of the trunk. Moreover, the total mass involved in a punch differs not only with the individual but also with the technique of boxer, depending on how much body weight is transferred to the punch. Furthermore, it is not known what differences exist in the generation of force or velocity based upon the level of a boxer. Likewise, very little scientific information is available concerning the forces generated from various punches of amateur boxers. Thus, knowing the fundamental mechanics of the three principal punches coupled with an investigation of the displacements, velocities and accelerations that can be generated may provide an indication of the forces generated in each type of punch.

Therefore, this study aimed to perform kinematic analysis of three principal punches in amateur boxing in order to provide useful information concerning the importance of the punch. It reveals what makes difference on the generation of force, and what velocities and accelerations can be generated by novice, intermediate and elite level boxers when performing three types of punches. This may later be used in estimating the forces generated and may provide basis for future scientist to use in the design and testing of the shock attenuation characteristics of gloves and protective head gear utilized in boxing.

1.2. Purpose of the Study

The main objective of this study was to determine differences, if any, in three-dimensional (3D) kinematic characteristics of the three principal punches (the jab, hook and uppercut) executed by novice, intermediate and elite level male amateur boxers. Specifically, the kinematic variables related to the displacement, linear velocity and linear acceleration of the upper body segments, translational hand acceleration and ground reaction force (GRF) generated by boxers were analyzed when they throwing the three different punches.

1.3. Significance of the Study

Boxing is composed of attack and defense, and the strategy is to hit faster, harder, and more effective and frequent blows while defending oneself better than the opponent (Unterharnscheidt, 1970). Consequently, an emphasis has placed on developing techniques that can disable an opponent. Therefore, the ability to deliver punches with effective technique both maximum force and also with speed are important considerations in amateur boxing (Dyson, Smith, Fenn & Martin, 2005). Together with physiological and psychological factors, the biomechanics of movement is an essential component in determining the impact force of a punch. Because, maximizing the impact force of punches is beneficial to all of the three main areas in boxing: sparring (free-fighting), patterns (forms) work, and in real competition.

Most of the boxing coaches and critics advocate that the jab is the most important and straight punch, and it is used as both an offensive and defensive weapon. The jab can also prevent the development of an attack by an opponent by keeping him off guard (Fitzgerald, 1980). The hook and uppercut, on the other hand, are intended to be power punches (Frazier & Dettloff, 2005). Accordingly, the ability to coach and train appropriately to deliver forceful punches is critical to success under the rules of competitive amateur boxing. But, what a shame that boxing instructors in Turkey have had little knowledge of muscular anatomy, kinesiology, training theory and biomechanics about effective technique and/or developing punch force. They have just practiced what they see and learn from their previous instructors, colleagues or other boxers.

Integration of technology and scientific disciplines such as engineering and kinesiology is now assuming a more important role in helping athletes gain the competitive edge. Some sports have used this integration to its benefits. Likewise boxing deserve to use this advantage to improve the punching techniques of practitioners. Once the critical factors most closely related to the impact force of punches are known, then training can be focused on developing these components. Specifically, those factors that are under the performer's control, once identified, can be emphasized during training. Depending on the kinematic variable that is identified, certain training strategies can be adopted to improve this particular aspect. As well as training programs, technique modifications may also be demonstrated to be beneficial in increasing the impact force of punches.

Therefore, the need for the present study focused around three main issues. Firstly, determining the kinematic factors that are contribute to a forceful punch is fundamental to the improvement of the techniques of amateur boxers. Secondly, there has been little scientific research conducted on kinematic characteristics of the three principal punches in boxing. Finally, knowing which factors are important in developing an effective punch enables practitioners and instructors to focus their training on developing these components.

1.4. Hypothesis of the Study

The hypotheses of this study are the followings:

1. Elite level boxers will generate larger shoulder, elbow and wrist displacement, linear velocity and linear acceleration compared to than those of intermediate and novice level boxers.
2. Elite level boxers will generate larger translational hand acceleration compared to intermediate and novice level boxers.
3. The uppercut punch will generate larger shoulder, elbow and wrist displacement, linear velocity and linear acceleration compared to the jab and hook punches in boxers.
4. The uppercut punch will generate larger translational hand acceleration compared to the jab and hook punches in boxers.
5. Vertical GRF of elite level boxers will be larger compared to intermediate and novice level boxers during a punch.

6. Vertical GRF at uppercut punch will be larger compared to the jab and hook punches in boxers.

1.5. Limitations of the Study

The following limitations were also acknowledged:

1. Only the best punches, in terms of technique and visibility from each camera, of each boxer were analyzed.
2. Subjects were given 10 minutes to complete a warm-up that they deemed to physically prepare them to perform full-power punches.
3. There was no control over whether or not the perceived maximal effort by subjects corresponded with the greatest impact force that they were capable of.
4. Verbal encouragement was considered to be equally motivating for all subjects to hit with full power.
5. It was considered that factors such as the day of the week, time of day, and the performer's physical condition did not affect subjects' performance.
6. Subjects were completely stationery at the beginning and end of the punching motion with both feet completely on the force platform.

1.6. Delimitations of the Study

A number of delimitations have been imposed by the investigator in order to test the research hypothesis:

1. The study was conducted in the Mo-cap Motion Capture Laboratory at Turkish Army Force-Middle East Technical University Modeling and Simulation Center at Middle East Technical University.
2. 10 novice, 9 intermediate and 11 elite level normal, healthy, male boxers were participated to this study.
3. The subjects ranged from 18 to 34 years of age.
4. The study was delimited to the three principal boxing punches performed by novice, intermediate and elite level boxers.
5. Only normal guarded boxers, i.e. right handed boxers, were used.
6. A standard punching bag at the subject's shoulder height and at a distance of the subject's own choice was used as the target for the punching.

1.7. Assumptions

The following assumptions were made for this study:

1. The participant's physical characteristics were representative of the general population.
2. The human body segments were assumed to be rigid bodies. The mass and moment of inertia of each segment about its mass center was constant during motion.
3. The joints were considered to be a pin joints.
4. The Normal punching movement pattern of the subjects was not altered appreciably by the imposed controlled condition while punching the bag.

5. Three-dimensional cinematography was a reasonably valid measurement technique for determining of displacement, velocity, acceleration and duration of punches.
6. The boxer's movements throughout the punch occurred primarily in the XY plane with respect to the camera position.
7. It was also assume that there were no carry-over effects from one punch to another, as it was instructed that the subjects had paused 10 seconds between trials when executing punches.
8. The properties of the punching bag were taken to be constant for all of the punches.

1.8. Definition of Terms

The following terms were established for the purpose of clarification:

1. **Novice level boxer:** A boxer from 17 to 34 years of age who had at least one year experience and never fought in an amateur boxing match.
2. **Intermediate level boxer:** A boxer from 17 to 34 years of age who had participated regional and national tournament.
3. **Elite level boxer:** A boxer from 17 to 34 years of age who had national amateur boxing title and had currently in the national team member.
4. **Stance or guard position:** The position whereby the feet were approximately shoulder apart. The left foot was about 15 to 20 cm forward and the trail foot was about 10 cm to the rear of the frontal plane of the body torso and both were in a sagittal plane. The left hand held at head height

while the right glove was held at chin height and both were lateral to the midline of the body.

5. **The Jab:** A short straight boxing punch delivered with the hand by forcibly extending the elbow with the rotation of the shoulder and thrusting the glove forward in the sagittal plane.
6. **The Hook:** A short and powerful blow delivered with a semi-circular motion of rotation of the shoulder and trunk by a boxer with the elbow flexed and rigid to the side of the opponent's head.
7. **The Uppercut:** A power punch thrusting upwards in a rising arc towards the opponent's chin or torso with the rotation of shoulder and trunk.
8. **Displacement:** The rate of change in position with respect to time.
9. **Velocity:** The rate of change in position with respect to time.
10. **Acceleration:** The rate of change in velocity with respect to time.
11. **Force:** The action of one body on another.
12. **Mass:** The quantity of matter composing a body.
13. **Kinematics:** The area of mechanics concerned with motion characteristics, and examines motion from a spatial and temporal perspective.
14. **Motion Analysis:** The use of video/computer-based instrumentation systems that test and measure human movement and/or movement of objects.
15. **Impact:** The collision of two bodies during a very short interval of time.
16. **Translational :** The motion in space of a point along a line.

CHAPTER II

REVIEW OF LITERATURE

In the sport of boxing, the force of impact and speed of the punch are considered the most important movement objectives. If the punching motion in boxing were measured kinematically and kinetically and compared, it might exhibit different characteristics. Therefore, a review of the biomechanical literature in the sport of boxing may contribute some knowledge and understanding to the different punching techniques and provide insight on the displacement, velocity, acceleration, and forces associated with punching.

In this chapter, the current literature review related with biomechanical research in boxing is presented. The literature review is divided into the following sections: (a) History of boxing, (b) Injuries in Boxing, and (c) biomechanical research regarding the kinematic and kinetic aspects of boxing,

2.1 History of Boxing

Boxing is one of the oldest forms of combat and of combat sports despite the fact that its rules and social importance have changed throughout the ages (Liponski, 2003). The oldest forms of boxing date back to ancient times and can be traced back over 5000 years to the King's Festivities in Ancient Egypt. Illustrations indicate that pugilists fought naked with a technique dependent upon one arm protecting the head and the other being used in attack (Prior, 1995). Paintings of boys fighting in Crete during 2000 BC reveal that helmets, the first type of head guard, were worn to protect the head and face from punishment and a glove to protect the attacking hand (Ellwanger, 1996).

The first Olympic pugilism took place at the 23rd Olympiad in Olympia in 688 BC. Pugilists wore a 3-metre narrow thong of leather around each hand and forearm, soaked in fat, which enabled them to make a glove called as a ‘cestus’. Since there were no rounds, the fight lasted until someone was defeated (McComb, 2004; Kluge, 1996). In Greece, at around 400 BC athletes become more competitive and contact sports, such as pugilism had a more violent nature. At this time the basic ‘stance’ and ‘on-guard’ position of the pugilist was developed (Prior, 1995). In 393 AD Emperor Theodosius-I banned the Olympic Games, with the number of pugilists declining until they eventually disappeared during the 4th century AD (Ellwanger, 1996). It is generally agreed that the Ancient form of pugilism re-emerged during the 17th Century as prize-fighting (Hickey, 1980).

The first set of boxing rules was introduced by Jack Broughton, in 1742, yet they did little to prevent the number of serious injuries and deaths resulting from prizefighting (Prior, 1995). In 1867, John Sholto Douglas, 9th Marquis of Queensbury, along with close friend John Graham Chambers, constructed a new set of rules to check the excesses of prize-fighting. In fact, the modern era in boxing was initiated by the introduction of the Queensberry Rules, which has important changes such as, contestants wore padded boxing gloves; there were three-minute rounds followed by one-minute rest intervals; wrestling became illegal; fighters who were knocked down had to rise unaided within 10 seconds; and it became illegal to go on hitting a man who was down (Hillman, 1980). One of the major rule changes was that fighters wore gloves and there was an attempt to match fighters according to body weight. The first regulated weight classification system in boxing was introduced in 1867 and was based upon the principle of making competition fairer by minimizing differences in body weight between competitors (Prior, 1995). During the period 1867-2002 the number of weight categories in Senior international amateur boxing increased from 3 to 12, ranging from light-flyweight (48 kg) to super-heavyweight (91+kg). However, in 2003 the 63.5 kg, 67 kg, and 71 kg divisions were replaced by a 64 kg and 69 kg category, resulting in the current 11 international senior competition weight classes (AIBA Technical & Competition Rules).

The duration of a boxing contest has undergone radical change since the Cotswold Games in 1634. Without regulation the length of many prize-fights lasted several hours with a time of 3-hours 15-minutes being recorded for the fight between Simon Byrne and James 'Deaf' Burke in 1833 (Miles, 1880). In 1880, the Amateur Boxing Association of England was formed and stipulated that the length of a contest would be restricted to 3 rounds. The recovery period between rounds was set at 1-minute. However, if the score of the contest was level after 3 rounds a fourth round of 2-minutes was allowed in order to determine a winner (Hickey, 1980; Prior, 1995). From an energy provision perspective this change in contest format increased the importance of energy supply from anaerobic sources. In 1926 the contest format was changed so that all contests took place over 3 rounds of 3-minutes duration with a 1-

minute interval between rounds. In 1997, the world governing body, AIBA, increased the number of rounds to 5 and decreased the duration of each round to 2-minutes. This change was not viewed positively. Under pressure from boxers, coaches and officials, the number of rounds was firstly reduced by AIBA to 4 prior to the 2000 Olympic Games. Then, the contest format was changed to old configuration again as 3 rounds of 3-minutes duration with a 1-minute interval between rounds (AIBA Technical & Competition Rules).

2.2 Injuries in Boxing

Although injuries in boxing are not the focal issue in this study, a superficial review of the literature on injuries is provided. This is done to provide the reader with a more comprehensive background on the issue of boxing safety. Participants in boxing as in most contact sports are at the risk of severe head impacts and brain injury (Gartland, Malik & Lowell, 2001). Therefore, medical and sports medicine journals have included the findings of numerous studies dealing with head trauma and brain injuries. There is consensus of opinion that the injuries to the head are caused by extreme linear acceleration of the brain in its cavity or rotational acceleration of the head which can rupture the many connecting veins, thereby causing a subdural hemorrhage. In many cases, the athlete is exposed to repeated impacts and injuries. In a 16 year follow-up study of injuries of professional boxers in Australia, 107 injuries were reported in 427 fight participations from August 1986 through to August 2001 (Zazryn, Finch & McCrory, 2003). The most commonly injured body region was the head, neck and face region (89.9%). The eye was the second most frequent injuries (45.8%) followed by concussions (15.9%) and mild traumatic brain injury (MTBI) (11.7%). Over 60% of injuries were classified as open wounds or lacerations generally to the head region (Zazryn, Finch & McCrory, 2003).

Moreover, risk factors, such as age and exposure, can increase the risk for injury. For amateur boxing competitions, the percentage of concussion injuries has been reported from 5.4% to 6.5% (Welch, Sitler & Kroeten, 1986; Jordan et al., 1997). Timm, Wallach, Stone & Ryan (1993) collected injury and illness data over 15 years in athletes who sparred, trained, or competed at the United States Olympic Training Center. This study recorded the occurrence of a concussion only 6.1% of all injuries.

The injury rate for amateur boxers was estimated to be 25 per 100 fight participations which is comparable to the injury rates seen in professional boxing (Zazryn. Finch & McCrory, 2003; Zazryn, Cameron & McCrory, 2006; Zazryn, McCrory & Cameron, 2009). The concussion injury rate for amateur boxers was calculated to be 3.1 per 100 fight participations which is much lower when compared to the rate calculated for professional boxers from the same study, 20.8 per 100 fight participations (Zazryn, Cameron & McCrory, 2006).

Although concussions are not as frequent in amateur boxing, studies have found that the repetitive impacts to the head, concussive and sub-concussive, sustained by boxers may generate neurological impairment (Matser, Kessel, Jordan, Lezak & Troost, 1998; Ng'walali et al., 2000; Warden et al., 2001; Garfield, 2002; Ravdin, Barr, Jordan, Lathan & Relkin, 2003). Acute injuries in contact and collision sports can result in functional alterations that range from MTBIs or concussions to death. In the literature, amateur and professional boxers have demonstrated some cognitive dysfunctions such as, information processing, verbal fluency, planning, attention, memory capacity, and reaction time when compared to baseline testing or control (Matser, Kessel, Jordan, Lezak & Troost, 1998; Warden et al., 2001; Ravdin, Barr, Jordan, Lathan & Relkin, 2003). Acute subdural hematomas are an additional concern to the boxing community because they are potentially fatal. Cases have been identified in the literature of boxers collapsing during a bout due to a subdural hematoma (Ng'walali et al., 2000; Garfield, 2002; Zazryn, McCrory & Cameron, 2009).

Acute injuries occurring from repeated blows to the head can be serious and may lead to a chronic issue. While severe acute injuries in boxing, including fatalities, are relatively rare compared with other sports (Zazryn, Cameron & McCrory, 2006), risk of chronic effects of brain injuries in boxing has been documented. Professional boxers are at much greater risk than their amateur counterparts, partly because they compete for longer and without head protection. Over a boxer’s career, repeated impacts to the head can lead to chronic traumatic brain injury which is also known as chronic traumatic encephalopathy or punch drunk syndrome (Corsellis, Bruton & Freeman-Browne, 1973; Corsellis, 1989; Roberts, Allsop & Bruton, 1990; McCrory, Zazryn & Cameron, 2007). Researchers have found that professional boxing may lead to chronic traumatic brain injuries (Corsellis, Bruton & Freeman-Browne, 1973; Corsellis, 1989; Roberts, Allsop & Bruton, 1990; Mendez, 1995; Jordan et al., 1997;

McCrory, Zazryn & Cameron, 2007). While research indicates that the syndrome is rare and appears in a less severe form in amateur athletes and other contact sports (Haglund & Eriksson, 1993; Moriarity et al., 2004; Loosemore, Knowles & Whyte, 2008). In addition, researchers have found evidence that the effects of repetitive concussions may be cumulative. Athletes with a history of multiple concussions report more signs and symptoms, demonstrate a lower baseline memory score, and experience a longer recovery period (Collins et al., 1999; Iverson, Gaetz, Lowell & Collins, 2003).

It is apparent that if the benefits of boxing are going to be maximized, the inherent dangers associated with head trauma must be reduced or eliminated. The frequency and severity of injuries can considerably reduce by better supervision, reduction in the number of competition a boxer fights each year, more heavily padded gloves, and other safeguards introduced by boxing authorities (Bledsoe, Li & Levy, 2005; Unterharnscheidt, 1970).

Based on some understanding of the nature of head trauma, the next section will emphasis on the biomechanical research in boxing.

2.3 Biomechanical Researches in Boxing

The mechanical effect of punches performed in boxing and martial arts has been studied on different ways and in some cases it was conducted more than 20 years ago. Unterharnscheidt and Sellier (1966) employed a simple experiment to measure the intensity of the blows in an actual bout, two physical education students, unskilled in boxing, fought for ten minutes using 12 oz. gloves, with accelerometers bandaged to their heads. The measurements obtained indicated that 21 blows accelerated the head by 0 to 5 g, 12 blows by 6-10 g, 3 blows by 11-15 g, 3 blows by 16-20 g, and 2 blows by 21-25 g. The first group of 21 blows included some defensive movements of the head that had the same effect as blows. The results correspond to those obtained for 16 oz. gloves in the model experiments. If the students had worn the 6 oz. gloves commonly used in professional contests, these values probably would have been at least twice as high. Had the subjects been professional boxers, capable of delivering more effective blows, the values would certainly have been higher. If this many blows hit the head in such a 10-minute fight, the equivalent of little more than 3 rounds, one must assume that the number of blows in a professional bout of 12 to 15 rounds would be at least several times greater.

Walker (1975) analyzed the amount of energy lost to deformation during impact and the impact forces imposed by the forward karate punch. He treated the strike as a collision between two free bodies. Results indicated that the maximum energy of about 165 Joules was delivered to the deformation of the opponent. The authors then calculated the stress created by the impact force to compare this to the maximum value that human bone can withstand. The results indicated that pine required 3111 N of force to rupture and brick required 3200 N. Human bone would require 3142 N to rupture under the conditions tested by the authors. Therefore, the research supported that a human bone could be fractured by an opponent's fast punch.

Feld, McNair, & Wilk (1979) investigated how the bare hand can break wood and concrete blocks without itself being broken. Motion pictures were taken at 1,000 frames per second in order to investigate the impact process. Four markers were placed on the wrist in order to determine velocities and accelerations. The front forward punch, downward hammer-first strike, downward knife-hand strike, roundhouse kick, wheel kick, front kick, and side kick were examined and peak speed was determined. In their study, peak speed of the front forward punch in karate recorded between 5.7 to 9.8 m/s., and downward hammer-fist strike was recorded between 10-14 m/s. The velocity data were used to determine the peak forces exerted on the first during impact. Since peak force was the product of the mass of the first (0.7 kg) and its deceleration (3.5-4 meters per second), the force was determined to be between 2.400-2.800 N. Results of the study indicated that a hand velocity of 6.1 m/s was needed to break wood and a hand velocity of 10.6 m/s was needed to break concrete. Authors suggested that the reason the bone in the hand does not break was due to the fact that bone was stronger than concrete. The rupture modulus of bone was 40 times greater than concrete. The hand was found to withstand more than 25,000 N of force to the bone and viscosity of connective tissues.

Jock, Fristche, & Krause (1981) examined different performance levels of seventy boxers. Kinematic and kinetic parameters, such as, punching force, ground reaction force, angle-time progress, and velocity of reaction and action were analyzed. A Kistler force platform measured the ground reaction forces. The impulses of punching were measured with a punch dynamometer. The elbow angles were measured with an electronic goniometer and the reaction times with reaction meter. One 16 mm camera was used to film the punching motion. The boxers were separated into three groups; 24 elite, 23 national league, and 23 intermediate boxers with no competitive experience. The straight punch was analyzed and results indicated that the punch force for the elite punchers was significantly different from the other two groups. The elite group’s punching force was 3453N, whereas the national league and non-competitive group punch forces were 3023N and 2932N, respectively. A correlation between punching force and body weight exited (r= .68). Although no difference was found between punching elbow angels among the groups, the distance of the punches in the non-competitive group were longer. The punch started at an elbow angle of 50-70 degrees and ended with an elbow angle 110-130 degrees at impact. The time to execute the punch was 100 ms on the average. The speed of action was different for the elite group as compared to the non-competitive group, 446 ms and 663 ms respectively. Average reaction times (427 ms) were four times larger than execution times. The authors concluded that boxers have little possibility of moving in enough time to avoid being punched.

Roy, Bernier-Cardou, Cardou & Plamondon (1984) examined the influence of bandages on the strength of impact of punches in boxing. The objective of the author's research was to compare the impact forces, which could be attained bare handed versus those obtained with different types of bandages, made up of gauze and diachylon. For the purpose of this study, 22 boxers were selected. The impact force was measured with a Kistler force plate, covered with a synthetic mattress. A system of photoelectric cells was used to measure the velocity of the punch. Each boxer had to impact the target with ten punches while his hand was covered with one of four types of bandages as well as bare handed. This study has shown that the bandaged hand significantly increases the impact force of a punch. The force increases in relation to the thickness of the bandage. The use of additional pieces of diachylon has a greater influence than gauze. Therefore, it can be concluded that bandaging increases the rigidity of the hand and facilitates the transfer of the force in comparison to a similar punch without a bandage or with a thinner one.

Donivan (1984) conducted a two-dimensional cinematographic analysis of the contribution of various biomechanical factors to the generation of force in boxing. Temporal and kinematic factors of the gloved fist for the three different punches, the jab, the cross and the hook, were examined. Variables used in the kinematic analysis included: (a) total and absolute displacement (cm), (b) duration (ms), (c) velocity (m/s), (d) acceleration (m/s^2). Nine male novice boxers representative of three weight categories, light (57-60 kg), middle (68-74 kg), and heavy (81-86 kg) were videotaped with high-speed cameras. The effect of glove weight (8, 12, and 18 ounces) on the variables analyzed was examined. The order of punching was not varied among the conditions tested; however, the authors randomized the glove weight order. High-speed cameras were used to collect data on all nine conditions tested (150 frames per second for the jab and the hook and 50 frames per second for the cross). The joint centers of the shoulder, elbows, and knuckles of each arm were estimated. Researcher found that the hook exhibited the highest velocity and acceleration when compared to the jab and the cross. The jab was the fastest punch when compared the hook and the cross. The jab also had the least amount of displacement when compared to the hook and the cross. The duration between all types of punches recorded differed significantly. The hook exhibited the greatest maximum impact velocity and acceleration. In conclusion, results indicated that body weight and glove weight had little influence on the kinematic parameters examined. However, type of punch had the greatest effect on the factors tested. Glove weight was also found to have little influence on these kinematic variables.

Atha, Yeadon, Sandover & Parsons (1985) designed an instrumented padded target mass suspended as a ballistic pendulum to determine the mechanical properties of a boxing punch. Data were gathered from a world ranked British professional heavyweight boxer who delivered a straight blow to the pendulum. The target was a cylindrical metal mass of 7 kg, estimated to be the mass of the head and neck of a heavyweight boxer. The punches were filmed by a 16 mm, variable shutter Bolex camera, at a nominal 64 Hz as well as a Hycam rotating prism camera operating at either 400 or 1.500 Hz. A millisecond timer and a fiducial system were included in the field of view, to permit the timing and scaling of events. Within 0.1 s of the start, the boxer’s fist had traveled 0.49 m and attained a velocity of 8.9 m/s on impact. The peak force was 4096 N (0.4 ton) on impact and was attained within 14ms of contact. Authors drawn attention to the shortness of the time taken to deliver the punch from first extension of elbow to peak contact. This represents a blow to the human head of up to 6320 N. The impulse accelerated the target head at the rate of 520 m/s^2 (53g). Only one boxer participated in the study so extrapolations to the general boxing population are not possible. However, the results reflect the force of a heavyweight boxer's punch, the model's biofidelity is unknown, and so the risk of injury cannot be determined.

Smith & Hamill (1985a) conducted a study on the impact characteristics of peak force, time-to-peak force, average force, and impulse at various velocities and repeated impacts of boxing and karate gloves. A mechanical impactor was used to eliminate mass variations found among boxers. The impactor was directed toward an AMTI force plate. The velocity varied by changing the glove position (height) before it was dropped. Significant differences were found between the karate glove and boxing glove on peak force (N), time-to-peak force (s), and impulse (N/s) ($p < 0.05$). In addition, all kinetic parameters were significantly different when compared across different velocities. The boxing glove surpassed the karate glove in magnitude of force variables, whereas the karate gloves surpassed the boxing glove on impulse and increasing velocities. At higher velocities the force was dissipated over a longer time for the karate glove. The boxing glove transmitted higher peak forces. Based on the results the authors suggested that karate punches are more likely to cause impacted objects to accelerate more than boxing gloves.

A second study conducted by Smith & Hamill (1985b) to determine the general trend of the kinetic parameters across 50 impact trials of a new glove. The velocity was not varied (2.0 m/s) and was only 8-21% of the velocities of human punchers. Boxing gloves were found to have higher peak forces occurring on the 50th trial as compared to the first trial, 2913 N and 1483 N respectively. A decrease in the gloves ability to attenuate forces was seen in the lower time-to-peak forces for both gloves. Impact forces were higher for the boxing glove when compared to the karate glove.

To assess the risk of injury from a boxer's punch, Smith, Bishop and Wells (1986) evaluated 3 amateur boxers. Each boxer was instructed to strike a headform with a left hook or left jab. The headform was instrumented with a 3-2-2-2 configuration of accelerometers to determine the linear and angular acceleration of the headform. From this study the linear acceleration for the left jab averaged 21.5 ± 4.6 g to 43.6 ± 15.6 g for the left hook. The angular acceleration varied from 202.7 ± 72.2 rad/s^2 for the left hook. Based on the tolerance limit of 200 g for linear acceleration and the recommended tolerance level of 4500 rad/s^2 for angular acceleration (Ommaya & Hirsch, 1971), the researchers concluded that neither the linear nor the angular acceleration reached a level that was highly dangerous to the boxer.

Smith & Hamill (1986) examined mechanical impact characteristics of the foam karate glove and conventional boxing glove in a punching situation. The velocities of low, intermediate, and highly skilled karate punchers were recorded. The fifteen karate participants were filmed punching barehanded (BH), with karate gloves (KG), and with boxing gloves (BG). High-speed cinematographic recordings with 100 frames per second were collected of the karate punchers. The joint centers were marked at the distal ends of the second and fifth metacarpals, media and lateral styloid processes, medial and lateral epicondyles of the femur and lateral malleous. Anthropometric measurements were taken, including limp and body segment lengths, participant height, and weight. The fists positions were digitized for twenty-one total frames. Using the finite difference method, fist velocities were calculated before impact and bag momentum was calculated after impact. The authors average the results from three trials per participant. Results indicated that the highly skilled participant generated more bag momentum than the intermediate or low skilled participants with 60.8 ± 17.3 Ns and 42.3 ± 11.6 Ns, respectively. The results showed no significant differences in fist velocities between skill levels or glove type (BF= 11.03 ± 1.96 m/s, KG= 11.89 ± 2.10 m/s, BG= 11.57 ± 3.43 m/s). Author hypothesized that the increase in bag momentum was due to the skilled boxer's ability to generate a greater effective mass during the impact than the lower skilled boxers. With the fist velocity at 11.5 m/s immediately before impact and the resultant bag momentum of 47.4 Ns, the effective mass of the striking fist was estimated to be approximately 4.1 kg. This is greater than the mass of the hand and reflects the ability to link more of the arm mass into the punch.

Schwartz, Hudson, Fernie, Hayashi, & Coleclough (1986) conducted a biomechanical study on full-contact karate contrasted with boxing. Accelerometers were mounted in a Hybrid dummy at the center of mass of the head. The outputs were sent to differential amplifiers and a digital storage oscilloscope stored the signal. The sampling rate was 12.8 kHz and 14 Participants were black belts in karate. Participants were instructed to hit the dummy from the side and from the front of the dummy's head with punches (bare fist, safety-chop, and with 10-ounce boxing gloves) and with kicks (bare foot and safety-kick). The maximum resultant acceleration (summation of sagittal and coronal accelerometer outputs) was determined. Results indicated that safety equipment did not reduce the acceleration of the dummy. However, 10-ounce boxing gloves reduced the peak acceleration. Kicks resulted in accelerations that lasted a greater length of time. Punches to the side of the head produced greater peak accelerations than punches to the front of the head. Punches using the back of the fist resulted in greater peak accelerations than kicks to the front or side of the head. The current study showed that safety equipment provides more protection for the person wearing it than the person being hit.

Whiting, Gregor, and Finerman (1988) examined three-dimensional coordinates of the boxer's shoulder, elbow, wrist, and glove to estimate linear and angular kinematics of the upper extremity. Four males proficient in boxing participate in the study. Two high-speed cameras synchronized and were positioned to film the boxers at 200 frames per second. The participants performed 20-30 punches of each condition, bare handed jab (BHJ), bare handed hook (BHH), gloved jab (GJ), and gloved hook (GH). The estimated joint centers were digitized. The DLT method was used to generate 3D coordinates from the 2D coordinates. An FFT-optimized data filtering system was used to smooth data, calculate velocity, and calculate acceleration for each point. Spatial geometry was used to calculate using the method of finite difference. Differences in gloved-punches versus bare-handed punches were insignificant. However, significant differences were found in the kinematic parameters examined for the jab and the hook. Shoulder and wrist velocities, elbow angle excursions, elbow angular velocities, and accelerations were chosen for the kinematic analysis. Regardless of the conditions under which the punches were performed, the hooks had the greatest magnitude in the most linear and the angular parameters. For shoulders, peak velocity occurred earlier in the punch cycle for the hooks than for the jabs ($p < .05$). Elbow peak velocity occurred earlier for the BHJ than for the GH. Wrist was higher for the GH than for the GJ. In summary, the peak velocity for the hooks was higher than for jabs. The range of velocities found for the shoulder, elbow, wrist, and hand/glove were 2.2-2.8 m/s, 5.7-6.0 m/s, 6.3-9.8 m/s, and 6.6-2.5 m/s, respectively. The hook exhibited the greatest magnitude of peak velocity in all conditions, BHJ, GH, and GJ. Minimum acceleration values of the shoulder were greater for the hooks than for the jabs. In addition, minimum acceleration values for the elbow were grater for the hooks (-143 m/s^2) than or the jabs (-95 m/s^2). On the other hand, maximum wrist accelerations were greater for the hooks than for the jabs. The jab had the highest angular velocity at contact when compared to the hooks.

Kreighbaum & Barthels (1996) wrote that the effectiveness of a punch relied on the accuracy of the punch and the instantaneous power at impact. The accuracy of the punch was affected by the displacement of the hand. Smaller linear displacement meant the punch arrived at the target sooner. Impact was defined as the collision of two bodies during a very short period of time and was determined by the instantaneous deceleration of the hand on the object. A large velocity of the hand at impact resulted in a large deceleration of the hand on the target.

Chiu & Shiang (1999) tested the following reverse punch, forward straight punch, and forward reverse punch. Three kinematic and kinetic parameters measured were reaction time, attacking speed, and punch force. Twelve participants who were black belts in karate participated in this study. The participants were instructed to punch the target suspended vertically. The accelerometer attached to the target measured the impact acceleration of the target. The reaction plate measured the time foot left the plate. The participant had to react as quickly as possible upon viewing the light. The straight and reverse punch showed no significant differences. Reaction time and attacking speed differed for both the standing punches and forward punches. The standing straight punch transfers force to a target by rotating the trunk and extending the arm. However, the forward straight punch moves the body forward and transfers the whole body momentum in force. Forward punches require more time to prepare pushing the body forward (550-650 ms). The standing punch required less time in preparation for transferring momentum to attack force (350-450 ms). When the authors examined the attacking speed they found that the forward punch had a faster attacking speed than the standing punch, 2.7-3.0 m/s and 1.9-2.1 m/s respectively. This result was due to the rear foot pushing the ground causing faster speeds in the forward punch.

Smith, Dyson, Hale & Janaway (2000) developed a boxing dynamometer and try to discriminate punch force efficiently. In developing this boxing dynamometer, they combined a triaxial force measurement system and a boxing manikin interface. The repeatability and accuracy of the dynamomoter were assessed using simulated straight punches. Discrimination efficacy was assessed by comparison of the maximal punching force of seven elite, eight intermediate and eight novice boxers during simulated boxing, throwing straight punches. For the elite, intermediate and novice groups, respectively, the maximal straight punching forces were 4800±227 N, 3722±133 N and 2381±116 N for the rear hand, and 2847±225 N, 2283±126 N and

1604±97 N for the lead hand. For all groups, maximal forces were larger for the rear than the lead hand ($P < 0.001$). Maximal punching force was greater in the elite than the intermediate group, and greater in the intermediate than the novice group ($P < 0.05$). The boxing dynamometer discriminated effectively between punching performance at three standards of performance and between the punching force of the rear and lead hands.

Girodet, Vaslin, Dabonneville & Lacouture (2005) conducted a study of two dimensional kinematic and dynamic analysis of a karate straight punch. They analyzed a straight punch struck by a karateka (1.68 m, 68 kg, 3rd dan black belt) on a training instrument traditionally used in makiwara technique in two dimensions. Anatomical markers were placed on the karateka according to a 12-segment model, and the scene was filmed at 125 Hz with a high-speed Photron digital camera. The impact force was measured at a 1 kHz sampling rate by two one-axis force sensors inserted into a target-block padded with dense synthetic foam and mounted on a flexible composite lath, which was vertically and rigidly fixed on the floor. The total horizontal linear momentum of the karateka's segments reached a maximum (26.11 $kg.m.s^{-1}$) before the impact and decreased by 2.58 $kg.m.s^{-1}$ during the contact time (0,015 s). The peak force (1745 N) measured by the target-block was reached 5 ms after the initial contact and the linear impulse produced during the contact time was 13.7 Ns.

Walilko, Viano & Bir (2005) studied the biomechanics of the head for punches to the jaw and the risk of head injury from translational and rotational acceleration. Seven

Olympic boxers from five weight classes delivered 18 straight punches to the frangible face of the Hybrid III dummy. Translational and rotational head acceleration, neck responses, and jaw pressure distribution were measured. High speed video recorded each blow and was used to determine punch velocity. According to the results of the study, punch force averaged 3427 (SD 811) N, hand velocity 9.14 (SD 2.06) m/s, and effective punch mass 2.9 (SD 2.0) kg. Punch force was higher for the heavier weight classes, due primarily to a higher effective mass of the punch. Jaw load was 876 (SD 288) N. The peak translational acceleration was 58 (SD 13) g, rotational acceleration was 6343 (SD 1789) rad/s2, and neck shear was 994 (SD 318) N. As a conclusion, Olympic boxers deliver straight punches with high impact velocity and energy transfer. Furthermore, the severity of the punch found to be increased with weight class.

A recent study by Stojsih, Boitano, Wilhelm & Bir (2008) collected in-ring head acceleration data from 30 female and 30 male amateur boxers during sparring sessions. Each participant wore an instrumented headgear during a practice bout and the head acceleration, injury criterion, duration, and location were recorded for each impact. They were the first to use a wireless telemetry system in the ring and compared the acceleration levels of male and female amateur boxers. Boxers were asked to wear an instrumented headgear developed by Simbex Inc. (Lebanon, NH). Real-time head acceleration data and head injury criterion where collected for each impact during the 4-two minute round sessions. In addition to collecting biomechanical data, cognitive data were collected before and twice after the session. This study found that there was no significant difference between the male and female head acceleration data and suggested that female amateur boxers were not at a greater risk for head injury when compared to male data. According to the authors force was a useful parameter in evaluating punch technique. Punch force was expressed by the impact acceleration of the target and the force was not directly measured. Moreover, the jab was significantly smaller in terms of force than the other two punch conditions and it required the least amount of time to execute. Three principal punches differed on motion time and total time to execute punch. In summary, kinematic and kinetic variables differed significantly among three types of punches.

CHAPTER III

METHODS

The purpose of this study was to determine differences, if any, in 3D kinematic characteristics of the three principal punches executed by novice, intermediate and elite level amateur boxers. With the kinematic variables measured using conventional motion analysis procedures, the punch forces were also estimated using accelerometer rather than direct force measurement.

3.1 Subjects

The subject group of this study was composed of 30 healthy, male amateur boxers: 10 Novice, 9 Intermediate, and 11 Elite levels. Descriptive characteristics of the subjects were presented in Table 1. Ages of the subjects ranged from 18 to 34 years old and experience of the subjects in boxing ranged from 1 year to 14 years.

Only right-handed participants were recruited for consistency and all participants were required to be free from injury in the upper and lower extremities. Due to skill level and technical difficulty, data from 30 participants were used in the analysis of three principal punches in boxing. Total of 90 punches were analyzed. The number and punch types for the subjects were 30 jabs, 30 hooks and 30 uppercuts. The data were categorized and analyzed by experience level (novice, intermediate and elite) and punch type (jab, hook and uppercut).

Table 1. Descriptive Characteristics of the Subjects

Group	*N*	Age	Weight (kg)	Height (m)	Experience (years)
Novice	10	22.50±4.09	74.40±13.48	1.82±0.07	2.11±0.93
Intermediate	9	23.11±5.84	76.67±13.23	1.77±0.05	5.19±2.14
Elite	11	22.73±1.42	74.64±21.62	1.78±0.10	9.6±2.29
Total	30	22.77±3.92	75.17±16.33	1.79±0.08	5.64±1.79

Informed Consent Form was included in Appendix A. Prior to participating in the study; all subjects received, and signed the informed consent form.

3.2 Data Collection Procedure

This study was conducted in Motion Capture (MoCap) Laboratory at Turkish Army Force-Middle East Technical University Modeling and Simulation Center at Middle East Technical University, Ankara, Turkey. Prior to the collection of data, the area of punching motion take place was calibrated with calibration wand. The subject order was randomly assigned. The anthropometric measurements including height, weight, and width of the segments were measured and recorded from each subject after the Informed Consent Form was signed. Height was measured by a vertical ruler, and body mass was measured using calibrated digital scales. Width of the body segments of each subject were measured with a Vernier Caliper between the anatomical landmarks as seen in Figure 1 and explanation of the anatomical landmarks were provided in Table 2.

Figure 1. Width of the some body segments were measured with Vernier Caliper

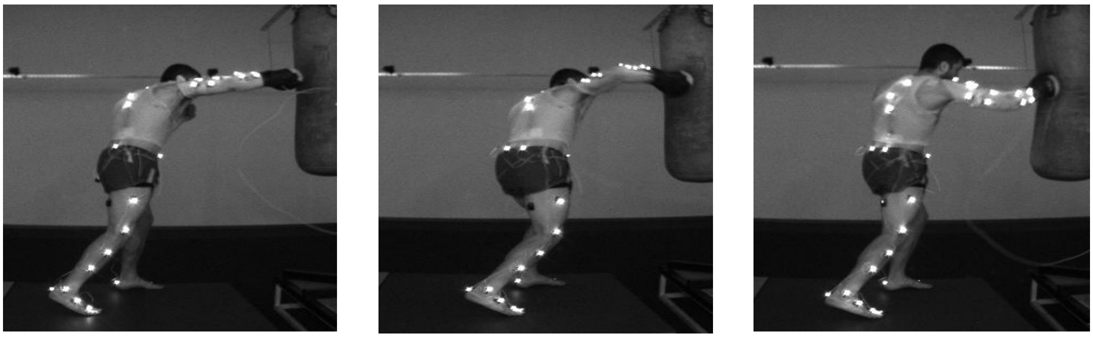
Table 2. Marker Placement for the Helen Hayes Marker Set Using Static Trials

Marker Description	Placement
Left and Right Toe	Center of the foot between the 2^{nd} and 3^{rd} metatarsals
Left and Right Foot	Proxilateral of right and left foot between 4^{th} and 5^{th} metatarsals
Left and Right Heel	Posterior Calcaneus at the same height above the plantar surface of the foot as toe marker
Left and Right Medial Ankle	Along the flexion/extension axis of rotation at medial malleolus
Left and Right Lateral Ankle	Along the flexion/extension axis of rotation at lateral malleolus
Left and Right Shank	On the lower shank below the midpoint, for greatest visibility by all cameras

Left and Right Medial Knee	Along the flexion/extension axis of rotation at medial femoral condyle
Left and Right Lateral Knee	Along the flexion/extension axis of rotation at lateral femoral condyle
Left and Right Thigh	On the lower thigh below the midpoint, for the greatest visibility by all cameras
Left and Right Iliac	Anterior Superior Iliac Spine
Sacrum	Superior Aspect at the L5-sacral interface
Back	Spinous process of the 7th cervical vertebrae Spinous Process of the 10th thoracic vertebrae
Sternum	5 cm under the Jugular Notch where the clavicles meet the sternum
Left and Right Shoulder	Tip of the Acromion Process
Upperarm Tracking Markers	4 cluster markers placed over the midpoint of the Humerus
Right Elbow	Lateral Epicondyle of the Humerus
Forearm Tracking Markers	4 cluster markers placed over the upper 1/3 of the Radius and Ulna

Right Wrist	Centered between the Styloid Processes of the Radius and Ulna

Anthropometric measurements and body segment parameters of the subjects were given in Appendix B. After the 5 minutes self-selected warm-up, 38 active LED markers were placed on the anatomically relevant locations such as, palpable bony landmarks near segment endpoints, and convenient locations for tracking the segments of the subjects according to the Helen Hayes model (Cappozzo, Cappello, Della Croce & Pensalfini, 1997). Then, a calibration file often referred to as a Standing Trial or Static Trial was obtained from the short motion capture of subject at the stationary pose. Then, the subject was asked to lightly strike the punching bag hanging from a platform mounted into the floor with their wrapped and gloved hand. The height of the bag was adjusted according to the shoulder level of the subjects. All the subjects hit on the marked point on the bag. If there was no pain or discomfort, they were asked to increase their punch force until they reached a point where they were throwing full power punches. Actually, there was no way of determining if the boxer was delivering his maximal punch force, but the competition that developed between the boxers led the researchers to believe that they were delivering punches with maximal effort. Once the subject was comfortable for throwing punch, they were instructed to strike the bag three times for each type of the punches with their dominant hand. The three principal punches performed in the order of jab, hook and uppercut as seen in Figure 2.



(a) (b) (c)

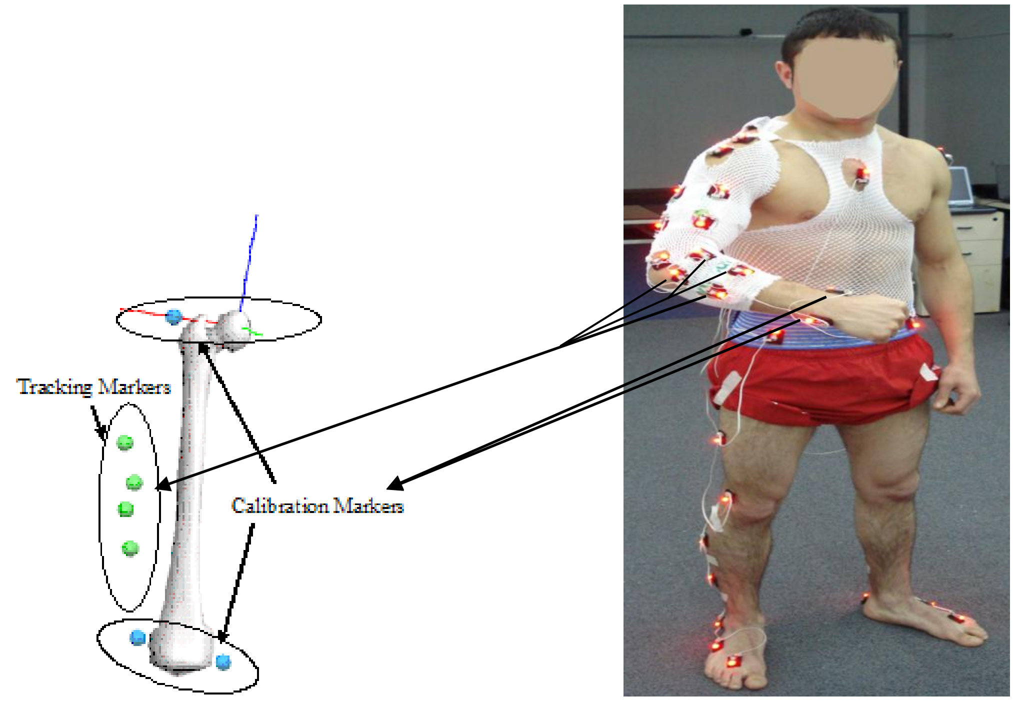
Figure 2. Three Principal Punches: (a) jab, (b) hook, (c) uppercut

The subjects performed the punches as soon as the “hit” signal comes from the researcher and wait 10 seconds between the punches to other hit signal comes. This allowed the boxers adequate time to recover after each punch and prepare for subsequent punches. Vertical GRFs were recorded using a force platform and translational hand acceleration was measured by an accelerometer which was placed in the palm of subjects and secured with hand wrap simultaneously. The 3-D coordinates of three principal punching motions of subjects was obtained by optical motion capturing system, and marker positions are averaged automatically over all frames to compensate for noise in the data. Then, the position data was used to create the models of the subjects and used to calculate kinematic variables. After the final punch, all markers, glove and accelerometer were removed.

3.2.1 Marker Placement

The markers were secured with double sided band to the body at anatomically significant locations that determine embedded axes for segments under consideration as seen in Figure 3. The number of markers used was arranged according to the importance of the segment motion. The Helen Hayes marker set is a relatively simple set of external markers developed for time-efficient video and kinematic analysis (Kadaba, Ramakrishnan and Wootten, 1990). Body motion analysis with this marker set does not require a static standing data capture for the calculation of body segment. However, the use of “optional” static trials greatly improves the accuracy in determining the ankle, knee, hip, wrist, elbow, shoulder joint centers and segment coordinate systems is highly recommended. This marker configuration minimizes the subject preparation and data acquisition time and reduces the number of trajectories that must be tracked or edited. The Helen Hayes marker sets determine joint centers and segment coordinate systems by means of calibration markers and set of tracking markers. It is important that the tracking marker set not move with respect to their original position on the subject's arm during data capture. If the tracking marker set move, the elbow and/or the wrist coordinate systems will move with them. Undetectable movement sometimes can cause large degrees of inaccuracy in joint kinematics and kinetics. Therefore we secured tracking markers firmly to do not move.

It was not feasible to attach a marker to the hand of a subject because of the gloved hand. The closest point to the hand was the wrist, where it was possible to attach a calibration marker and it removed before the strike so that it would not bother the subject. If the wrist markers were used, it was not possible for the cameras to observe the motion of the wrist joint. Therefore, after the static trial, calibration markers were removed.



(a) (b)

Figure 3. a) Calibration and tracking markers, b) marker placement

3.3 Instruments

In order to obtain kinematic characteristics of three principal punches in amateur boxing, the use of the following instruments was necessary.

3.3.1 Force Platform

Force platforms have been specifically designed for gait, balance, sports and other static and dynamic analyses. They have generally six component load transducers in each corner, which measure the three orthogonal components of the resultant force acting on the plate and the three components of the resultant moment in the same orthogonal coordinate system shown in Figure 4. Design and size of the force platforms can be change according to the researchers' requirements. In order to collect kinematic data and the ground reaction forces, a 120x120 cm custom made Bertec Force plate (Bertec Corp., Columbus, CA, USA) consists of 4 strain gauge load transducer and built in a digital pre-amplifier (model AM6500) for signal conditioning was used in this study.

The measured signals coming from four strain gauge based force transducers were amplified, filtered, and digitized in the force plate, which minimizes signal degradation due to external noise sources during analog signal transportation. The output of the force plate was a 16-bit single channel, serial, digital signal, which could be transported over very long distances without any loss of quality. The digital output was directly connected to the USB port of the computer, and converted into six individual analog signals to be connected to an Analog/Digital (A/D) card. The signals were displayed and recorded by the Digital Acquire program provided by manufacturer. In the A/D conversion each channel was sampled at 1000 Hz with a range of 5V and the reading in Volts was converted to Newtons according to the calibration matrix set by the manufacturer, the bridge excitation, and the gain. Finally, the point of application of the force and the couple acting on the plate can be readily calculated from the measured force and moment component (Bertec User Manual, 2010)

The subject was instructed to punch upon hearing a verbal command. As this command was given, a signal simultaneously triggered the Digital Acquire software to record the force platform data from 1 s before until 5 s after this trigger. This was to give the subject time to retract the punch and then come back to rest with both feet completely on the force platform. When performing a maximal effort technique in any form of training or competition, boxers are expected to retain balance during and after completion. Therefore, the condition that boxers must begin and finish stationery position was realistic. The target area on the bag was positioned at a height equal to the subject's shoulder level, and at a distance that they deemed to be suitable for punching.

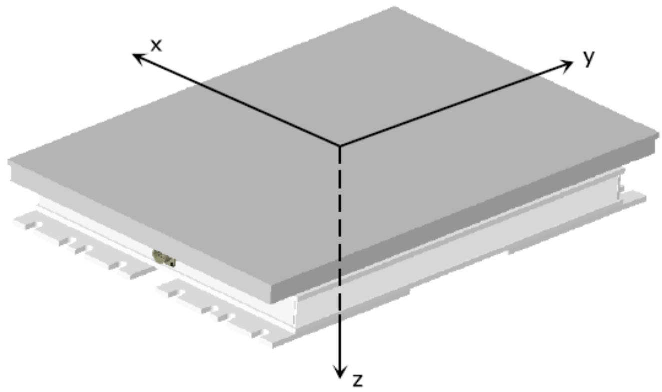


Figure 4. Coordinate system for load measurements. The center of the coordinate system is at the inner corner of arm block with y-axis forward, x-axis to the left (pointing inwards looking from behind), and z-axis downward.

Source: Adopted and used with permission from Bertec Corp., 2010.

3.3.2 Accelerometer

In biomechanical research, reaction forces are usually measured by force plates mounted on an immovable surface. However, in this study it would not be possible for the subjects to exert their maximum force in punching that type of solid surface because of the potential for injury. In addition, the kinematics would likely be different with respect to punching an immovable surface as compared to punching a human body. For this reason, a standard punching bag was used to measure kinematic data of three principal punches in boxing.

One ADXL193 ±250g capacities single axis accelerometer was used to measure hand acceleration of boxers in this study. The ADXL193 is a fourth-generation surface micromachined *i*MEMS based accelerometer from ADI with enhanced performance and lower cost. The accelerometer was secured to the boxer's right hand by embedding it in the boxer's hand wrap as illustrated in Figure 5.

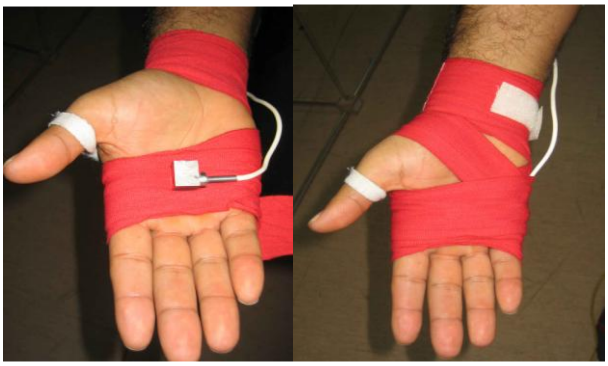


Figure 5. Accelerometer inserted into the hand.

This fixation method did not rigidly attach the accelerometers to the hand but did provide a good method of predicting the overall hand acceleration. As soon as the movement starts, signals coming from the accelerometer were sent to the signal conditioner. This amplifier was utilized for signal conditioning with a gain of 10. The amplified signals were sent to a terminal accessory board and to a PC over an A/D converter. The A/D board was set at ±5 volts of input range in bipolar mode. The software written by manufacturer was used to collect acceleration data. The program collected data from the accelerometer in digital units at a sampling frequency of 1000

Hz with the duration of 5 seconds for each trial. Then acceleration data coming from digital units converted to a data file to derive resultant acceleration just before the impact and data were smoothed using Butterworth digital filter.

3.3.3 PhaseSpace Motion Capture System

Operationally, the PhaseSpace motion capture system (Phase Space Inc., San Leandro, CA, USA) uses multiple cameras to triangulate the location of multiple LED’s. At a distance of 10 meters the system has a practical resolution of 10 mm. The system consists of multiple CCD (charge coupled device) cameras that detect the presence of each LED 480 times per second. PhaseSpace Motion Capture System (PMCS) was used to obtain 3-D coordinates of three principal punching motions of subjects. The motion was captured with a real time optical tracking system with 8 high speed cameras which was perpendicular each other with 90 degree at a frequency of 240Hz. PMCS was designed to drastically reduce the number of errors in the data, thus reducing the cost of data cleaning. As seen Figure 6, PMCS uses standard Cat-5 cables to connect between the cameras, base station, and server. Each server, using a quad core processor, can connect and power up to 48 impulse cameras. The base station provides an RF signal to the LED controller. The RF channels can be adjusted to circumvent any radio interference. Each LED controller can drive a maximum of 72 active LEDs (PhaseSpace User Manual, 2010).

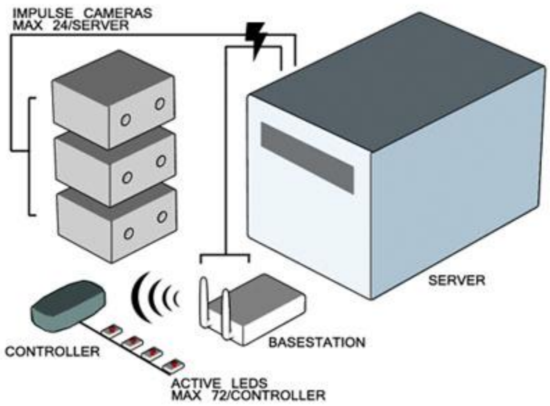


Figure 6. Components of Phase Space motion capture system
Source: Adopted and redrawn with permission from PhaseSpace Inc., 2010.

The PMCS has six components; Impulse cameras, led base station, server computer, led controller, impulse active led and calibration wand. Each component is modular and allows the system to scale without a penalty in performance. Components of the system were explained followings in details.

3.3.3.1 Impulse Cameras

The system consisted of the eight impulse cameras and each camera achieves an Optical Resolution of 3600 x 3600 (12 megapixel) and using two linear detectors without sacrificing any speed in processing with 16-bit dynamic range as seen in Figure 7. It has also onboard processors produce an impressive sub-pixel resolution of 30,000 x 30,000 at 480 Hz. Its superior resolution is paired with a 60 degree Field-of-View, enabling users to capture from within small spaces.

Figure 7. Front and back view of an impulse camera.

Source: Adopted and used with permission from PhaseSpace Inc., 2010.

3.3.3.2 Led Base Station

The Led Base Station with 2.4 Ghz Transceiver, as seen in Figure 8, provides an RF signal to the LED controller and outputs outside time source with the server.

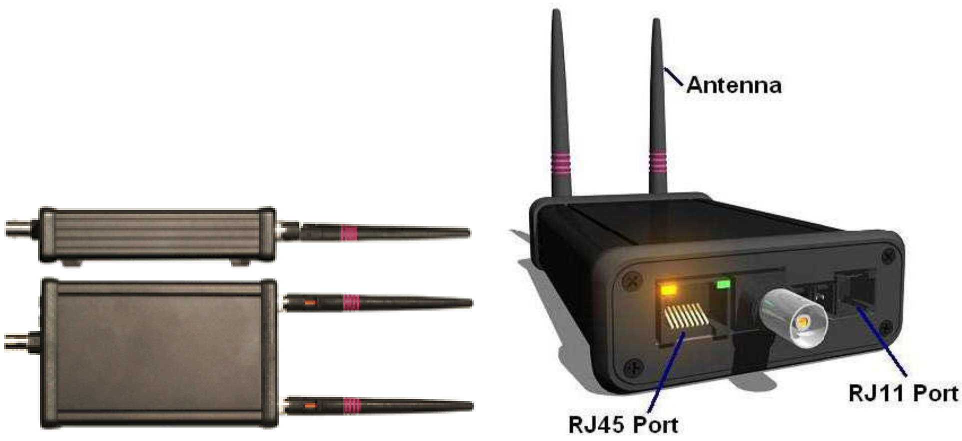


Figure 8. Side, top and back view of a led base station

Source: Adopted and used with permission from PhaseSpace Inc., 2010.

3.3.3.3 Server Computer

The entire impulse motion capture system runs efficiently on a single server computer as seen in Figure 9. Utilizing the latest quad core processor, the server machine collected and processed data from up to 48 cameras. The server outputs 3D position data at 480 frames per second with below 10ms latency.

Figure 9. Front and back view of server computer
Source: Adopted and used with permission from PhaseSpace Inc., 2010.

3.3.3.4 Led Controller

As seen in Figure 10, the Led Controller, actually an RF transceiver, is utilized an onboard microprocessor to control up to 72 Leds. Battery life is 2 to 4 hours of continual use, up to 8 hours of typical use. The Impulse system can use multiple LED Controllers simultaneously.

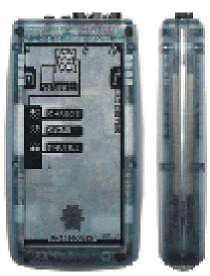


Figure 10. Front and side view of led controller.
Source: Adopted and used with permission from PhaseSpace Inc., 2010.

3.3.3.5 Impulse Active Led

Each LED modulated from 30 to 480 Hz frequency resulting in a unique digital ID. Ultra-bright Red LED, customizable to Infra-Red (IR), Blue, Green, or Yellow versions. It has 20 mm x 14 mm x 3.2 mm dimension and 4.5 grams weight as seen in Figure 11.

Figure 11. Impulse active led comparison with a join
Source: Adopted and used with permission from PhaseSpace Inc., 2010.

3.3.3.6 Calibration Wand

The calibration wand as seen in Figure 12 serves as the principal tool used to accurately calibrate the system. Using 8 LEDs, the calibration wand allows a user to calibrate the given capture area in a matter of minutes.

Figure 12. Calibration wand
Source: Adopted and used with permission from PhaseSpace Inc., 2010.

PMCS was calibrated with the calibration wand before each trial. A calibration file often referred to as a Standing Trial or a Static Trial, is a short motion capture of the subject in a stationary pose. Marker positions obtained from PMCS and then the errors and glitches in motion capture data were clean up by using Recap software developed by Phase Space Inc. A major component of Recap is Skeleton, a tool used on collected data to find and maintain proper joint locations on the human body. Skeleton implements a constraint system where, even when markers were occluded during the capture. Data were fitted with quintic spline functions and the function was used to interpolate the data to fill the gaps flawlessly, generating extremely fluid human movement. 3-D coordinates of the motions obtained from PMCS was smoothed using 6 Hz Butterworth digital filter. Data are averaged automatically over all frames to compensate for noise in the data.

3.3.4 Visual 3D Biomechanical Analysis and Modeling Software

Modeling and Kinematic calculations of the three principal punches in boxing were realized by Visual3D Biomechanical Analysis and Modeling Software (C-Motion Inc., Germantown, MD, USA). 3D motion data captured and exported from PMCS was associated with the model created. Visual3D Biomechanical Analysis and Modeling Software was used to create a model of the subjects using a standing calibration trial and define the linked segments as seen in Figure 13. The body segment parameters within the model were defined using anatomical and tracking markers. The body segments used to create model were the foot, leg, thigh, hip, trunk, shoulder, upper arm, forearm, and the wrist. Then the biomechanical model-based parameters such as joint displacements, linear velocities and accelerations were defined and calculated.

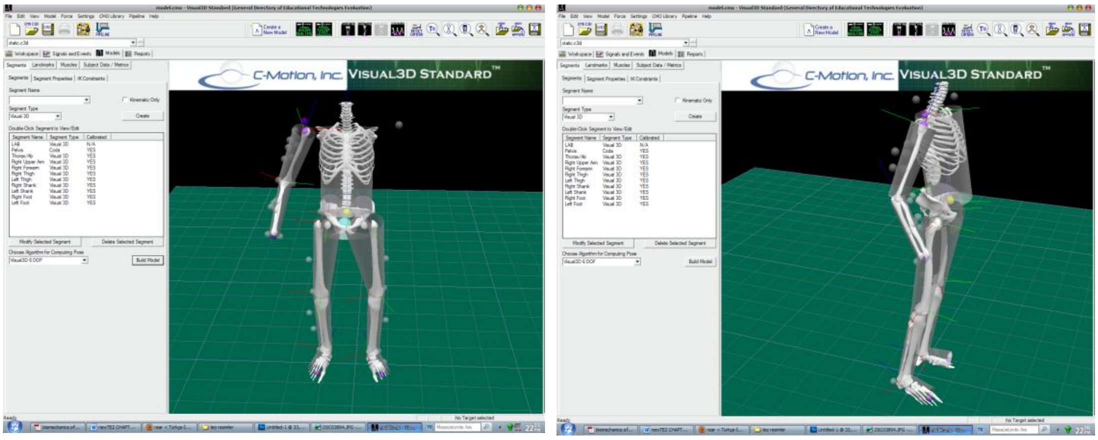


Figure 13. Standing calibration trial in Visual 3D software

3.3.5 Boxing Glove

The 10-ounce conventional, certified foam filled competition type boxing glove was used in this study.

3.4 Statistical Analysis

Kinematical data were analyzed using Statistical Package for the Social Sciences (SPSS) 18.0.1 (PAWS statistics Inc., USA). 3 (experience level) x 3 (punch type) factorial ANOVA design were used to see whether the factor effects of the experience level or punch type on the kinematic variables separately. If a statistically significant difference was found, experience level and punch types were then compared with Tukey HSD (Honestly Significant Difference) post-hoc test. But, the interaction effect does not indicate where the differences are. Therefore, if a significant interaction was found between experience level and punch type, firstly, mean differences between each punch type and experience level was compared. Then, each experience level between the punch types was compared. Thus, within and between group comparisons were performed for three different punches.

The independent variables included experience level and punch type, and the dependent variables consisted of displacement, linear velocity and linear acceleration of shoulder, elbow and wrist separately, translational hand acceleration and vertical GRF.

A Pearson Correlation test was used to analyze descriptive characteristics of subjects. The Pearson Correlations were administered separately for the punch types and Alpha level was set at $p < 0.05$.

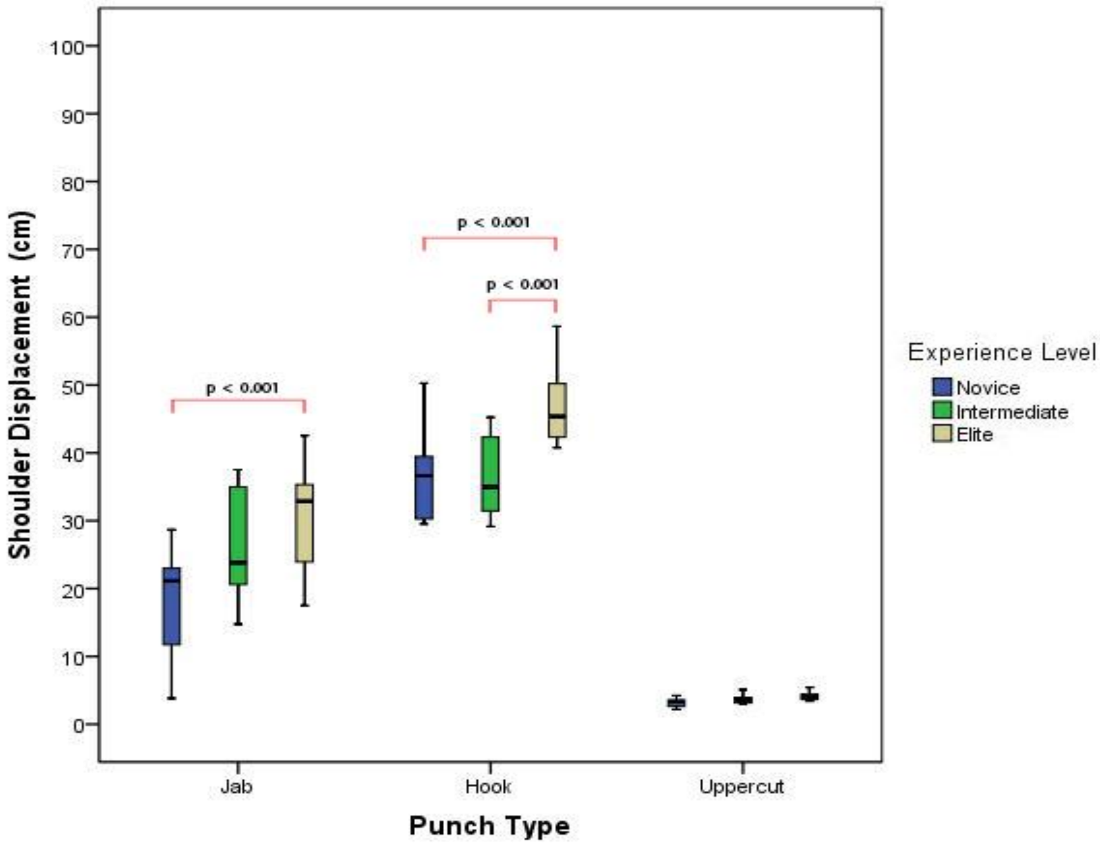
CHAPTER IV

RESULTS OF DATA

The present study was undertaken to examine the effects of experience level on the displacement, linear velocity and linear acceleration of the shoulder, elbow and wrist, translational hand acceleration and vertical GRF for three principal boxing punches (jab, hook and uppercut) in amateur boxers. Displacement, linear velocity and linear acceleration data were quantified to determine these effects. This chapter presents the results of the study and is divided into five sections. Because all measures and calculations were made on the basis of displacement data, the results of these analyses are reported in the first section. These analyses are then followed by sections presenting the results of linear velocity, linear acceleration, translational hand acceleration, and lastly vertical GRF. Each major section includes the explanation of differences due to punch type and experience level in details.

4.1 Displacement Data

According to the post-hoc analysis, the main effect of experience level on shoulder displacement was significant, $F(2,81) = 217.6$, $p < 0.001$. According to the results, elite level boxers generated larger shoulder displacement than that of intermediate and novice level boxers at the hook punch. Moreover, elite level boxers generated larger shoulder displacement than that of novice level boxers at the jab punch (Figure 14).



Figue 14. Mean shoulder displacement of the subjects according to the experience level and punch type (p indicates significance level)

Post-hoc analysis showed that the main effect of punch type on shoulder displacement was significant, $F(2,81) = 9.33$, $p < 0.001$. Although, the uppercut punch did not generate larger shoulder displacement compared to the hook and jab punch in boxers, the hook punch generated larger shoulder displacement compared to the jab and uppercut punches in boxers. Moreover, the jab punch generated larger shoulder displacement compared to the uppercut punch in boxers (Figure 14).

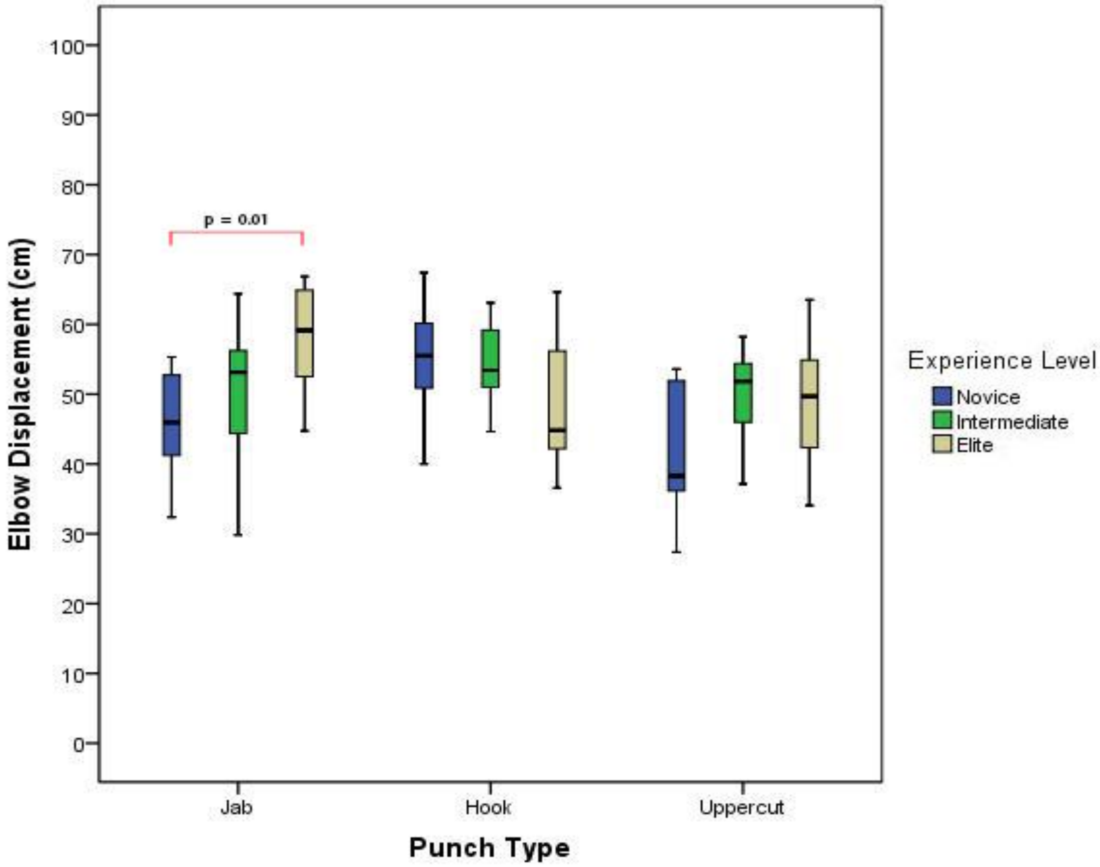


Figure 15. Mean elbow displacement (cm) of the subjects according to the experience level and punch type (p indicates significance level)

Post-hoc analysis showed that the main effect of experience level on elbow displacement was significant, $F(2,81) = 4.91$, $p = 0.01$. According to the results, elite level boxers only generated larger elbow displacement than that of novice level boxers at the jab punch (Figure 15).

According to the results of post-hoc analysis, the main effect of punch type on elbow displacement was not significant, $F(2,81) = 2.35$, $p = 0.1$. Therefore, the uppercut punch did not generate larger elbow displacement compared to the jab and hook punch in boxers (Figure 15).

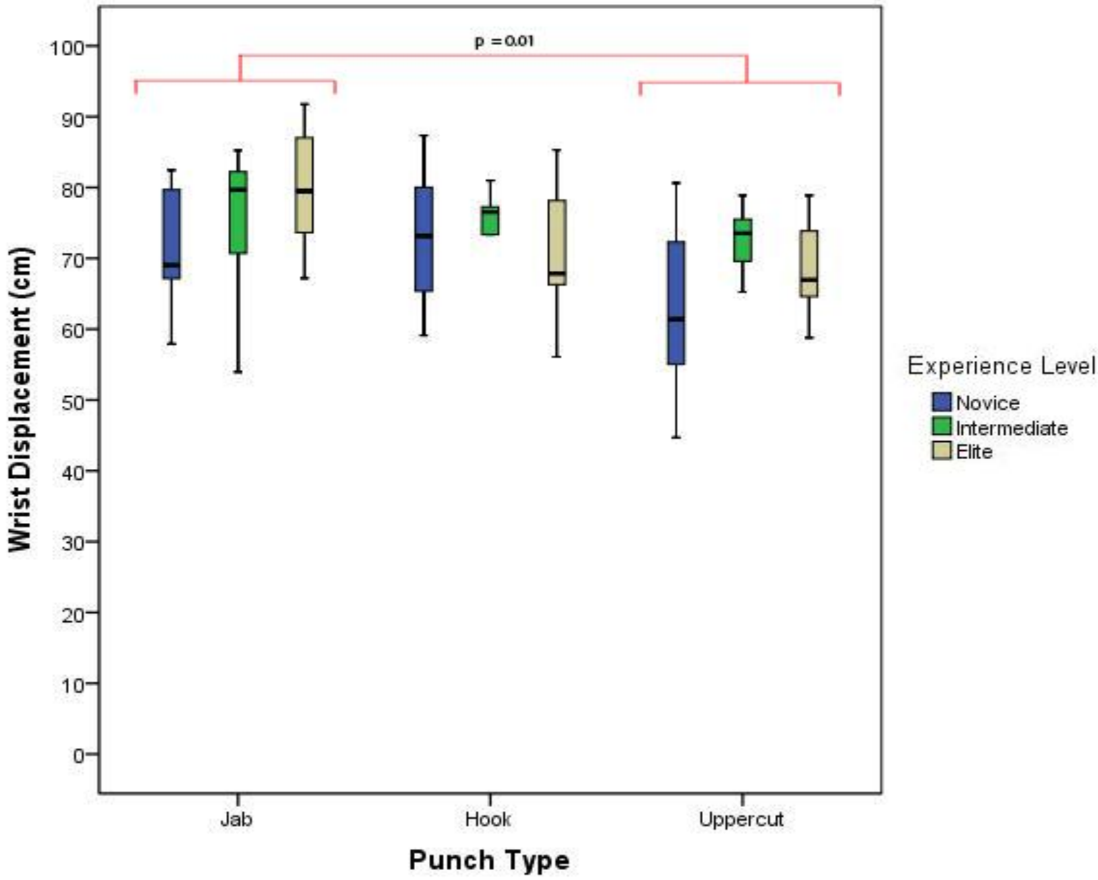


Figure 16. Mean wrist displacement (cm) of the subjects according to the experience level and punch type (p indicates significance level)

Post-hoc analysis showed that the main effect of experience level on wrist displacement was not significant, $F(2,81) = 2.52$, $p = 0.09$. According to the results, elite level boxers did not generate larger wrist displacement than that of novice level boxers at the hook punch (Figure 16).

According to the results of post-hoc analysis, the main effect of punch type on wrist displacement was significant, $F(2,81) = 5.25$, $p = 0.01$. The results of analysis showed that the jab punch generated larger wrist displacement compared to the uppercut punch in boxers (Figure 16).

4.2 Linear Velocity Data

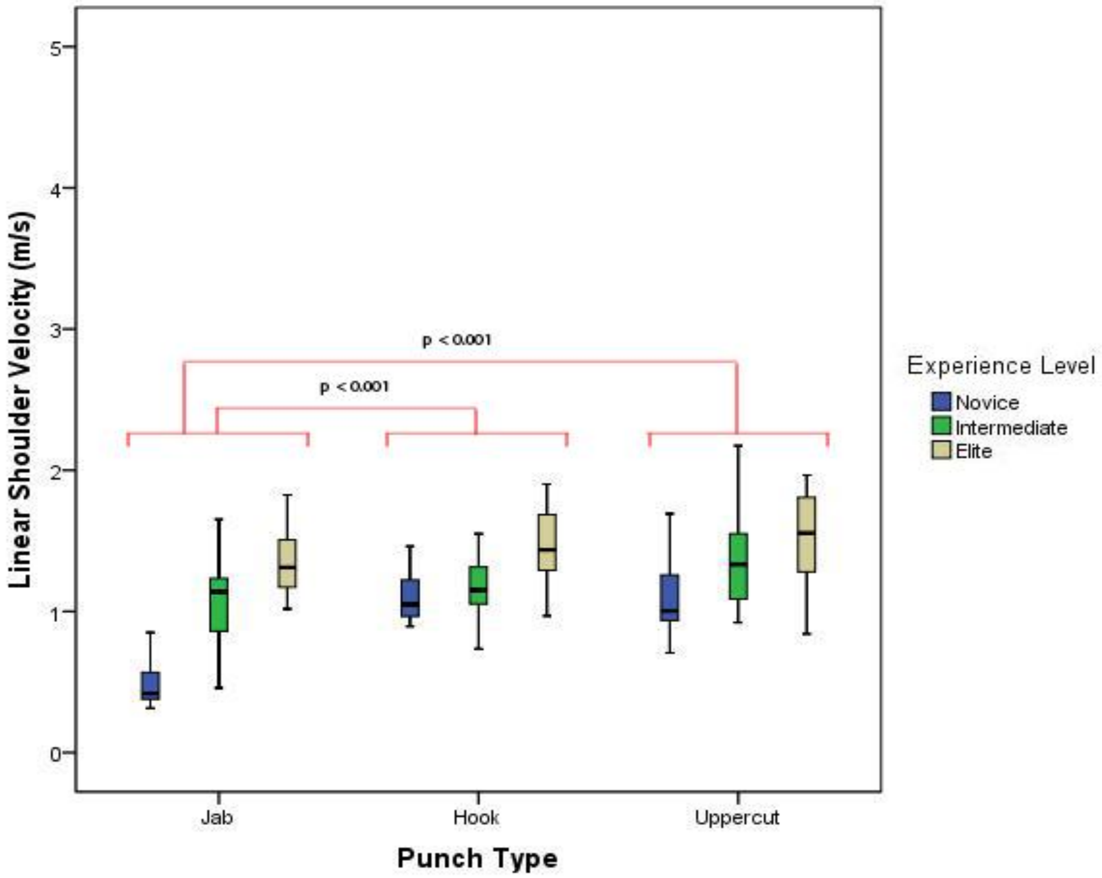


Figure 17. Mean linear shoulder velocity (m/s) of the subjects according to the experience level and punch type (p indicates significance level)

Post-hoc analysis showed that the main effect of experience level on linear shoulder velocity was significant, $F(2,81) = 9.4$, $p < 0.001$. According to the results, elite level boxers generated larger linear shoulder velocity than that of intermediate and novice level boxers (Figure 17).

According to the results of post-hoc analysis, the main effect of punch type on linear shoulder velocity was significant, $F(2,81) = 24.0$, $p < 0.001$. The results of analysis showed that the uppercut punch generated larger linear shoulder velocity compared to the jab punch in boxers. Moreover, the hook punch generated larger linear shoulder velocity compared to the jab punch in boxers (Figure 17).

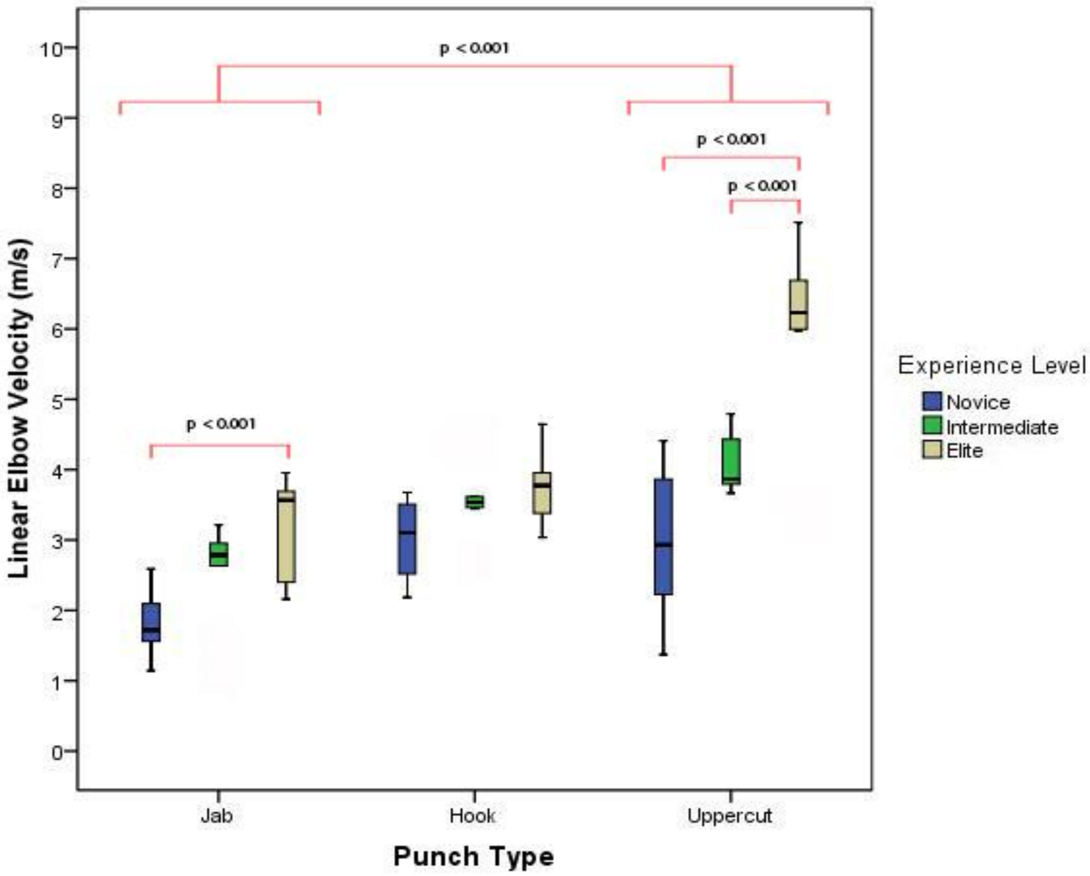


Figure 18. Mean linear elbow velocity (m/s) of the subjects according to the experience level and punch type (p indicates significance level)

Post-hoc analysis showed that the main effect of experience level on linear elbow velocity was significant, $F(2,81) = 40.4$, $p < 0.001$. According to the results, elite level boxers generated larger linear elbow velocity than that of intermediate and novice level boxers at the uppercut punch. Similarly, elite level boxers generated larger linear elbow velocity than only that of novice level boxers at the jab punch. However, elite level boxers did not generate larger linear elbow velocity than that of intermediate and novice level boxers at the hook punch (Figure 18).

According to the results of post-hoc analysis, the main effect of punch type on linear elbow velocity was significant, $F(2,81) = 44.4$, $p < 0.001$. The results of analysis showed that the uppercut punch generated larger linear elbow velocity compared to the hook and jab punch in boxers (Figure 18).

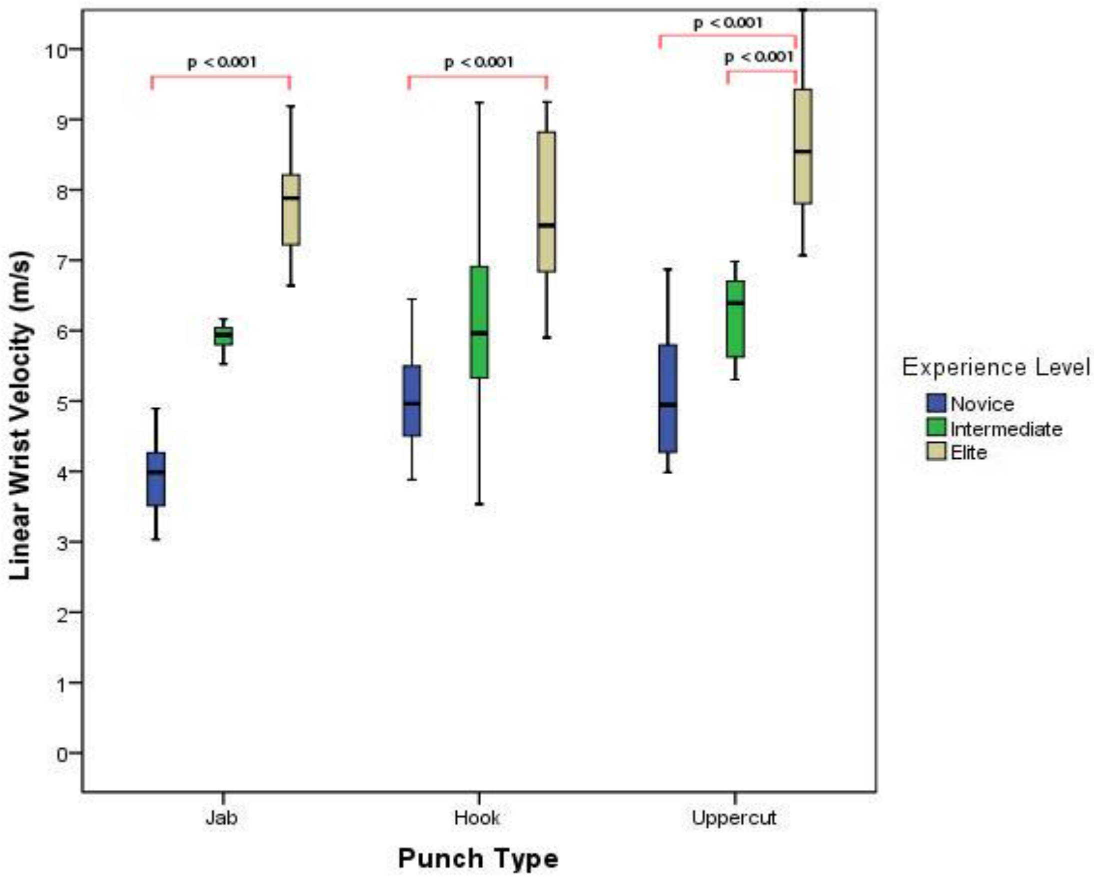


Figure 19. Mean linear wrist velocity (m/s) of the subjects according to the experience level and punch type (p indicates significance level)

Post-hoc analysis showed that the main effect of experience level on linear wrist velocity was significant, $F(2,81) = 75.4$, $p < 0.001$. According to the results, elite level boxers generated larger linear wrist velocity than that of intermediate and novice level boxers. Moreover, intermediate level boxers generated larger linear wrist velocity than that of novice level boxers. (Figure 19).

According to the results of post-hoc analysis, the main effect of punch type on linear wrist velocity was significant, $F(2,81) = 5.4$, $p = 0.01$. The results of analysis showed that the uppercut punch generated larger linear wrist velocity compared to the jab punch in boxers (Figure 19).

4.3 Linear Acceleration Data

Post-hoc analysis showed that the main effect of experience level on linear shoulder acceleration was significant, $F(2,81) = 36.8$, $p < 0.001$. According to the results, elite level boxers generated larger linear shoulder acceleration than that of intermediate and novice level boxers (Figure 20).

According to the results of post-hoc analysis, the main effect of punch type on linear shoulder acceleration was significant, $F(2,81) = 25.3$, $p < 0.001$. The results of analysis showed that the uppercut punch generated larger linear shoulder acceleration compared to the hook and jab punch in boxers (Figure 20).

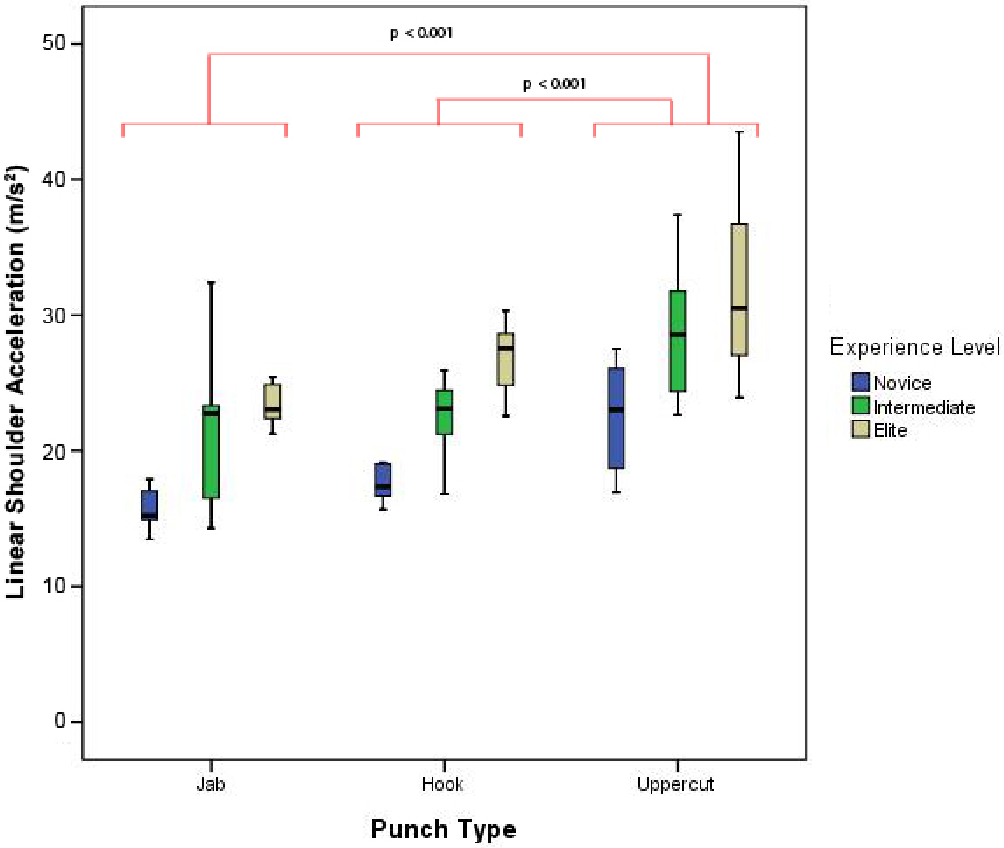


Figure 20. Mean linear shoulder acceleration (m/s^2) of the subjects according to the experience level and punch type (p indicates significance level)

Post-hoc analysis showed that the main effect of experience level on linear elbow acceleration was significant, $F(2,81) = 107.0$, $p < 0.001$. According to the results, elite level boxers generated larger linear elbow acceleration than that of intermediate and novice level boxers at the uppercut punch. Moreover, elite level boxers generated larger linear elbow acceleration than that of intermediate and novice level boxers at the hook punch (Figure 21).

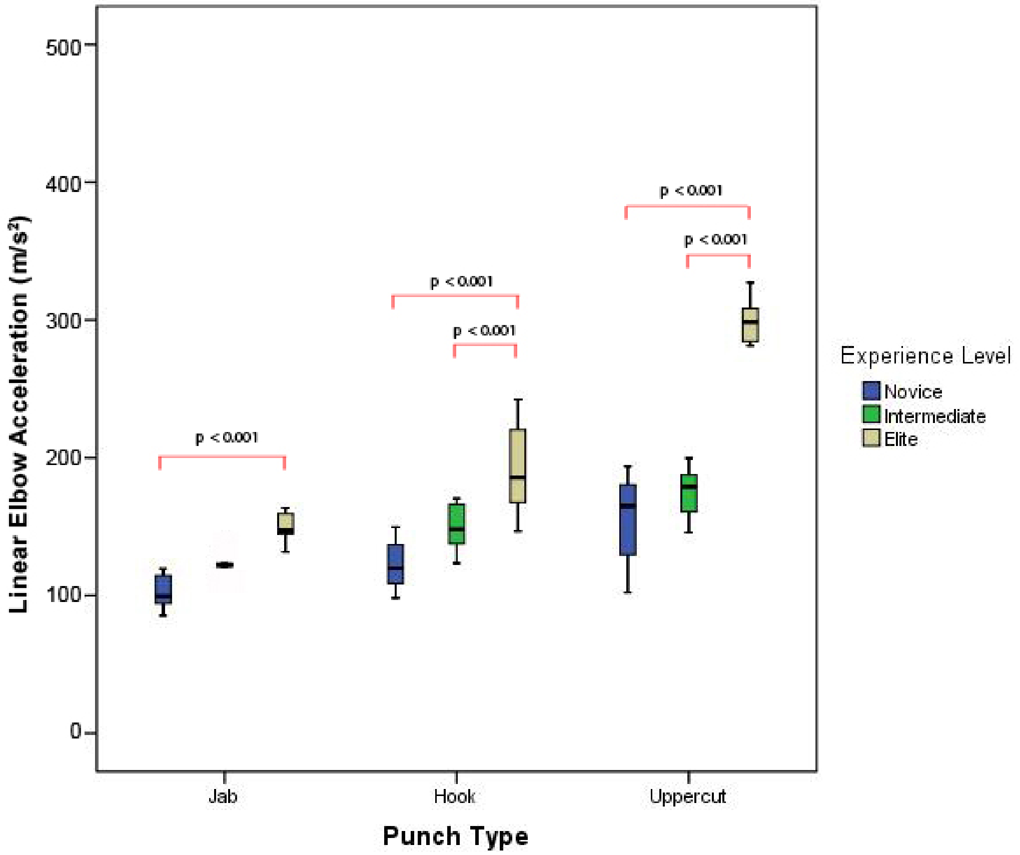


Figure 21. Mean linear elbow acceleration (m/s^2) of the subjects according to the experience level and punch type (p indicates significance level)

According to the results of post-hoc analysis, the main effect of punch type on linear elbow acceleration was significant, $F(2,81) = 84.5$, $p < 0.001$. The results of analysis showed that the uppercut punch generated larger linear elbow acceleration compared to the hook and jab punch in boxers (Figure 21).

Likewise, the main effect of experience level on linear wrist acceleration was significant, $F(2,81) = 84.0$, $p < 0.001$. According to the results, elite level boxers generated larger linear wrist acceleration than that of intermediate and novice level boxers at the uppercut punch.

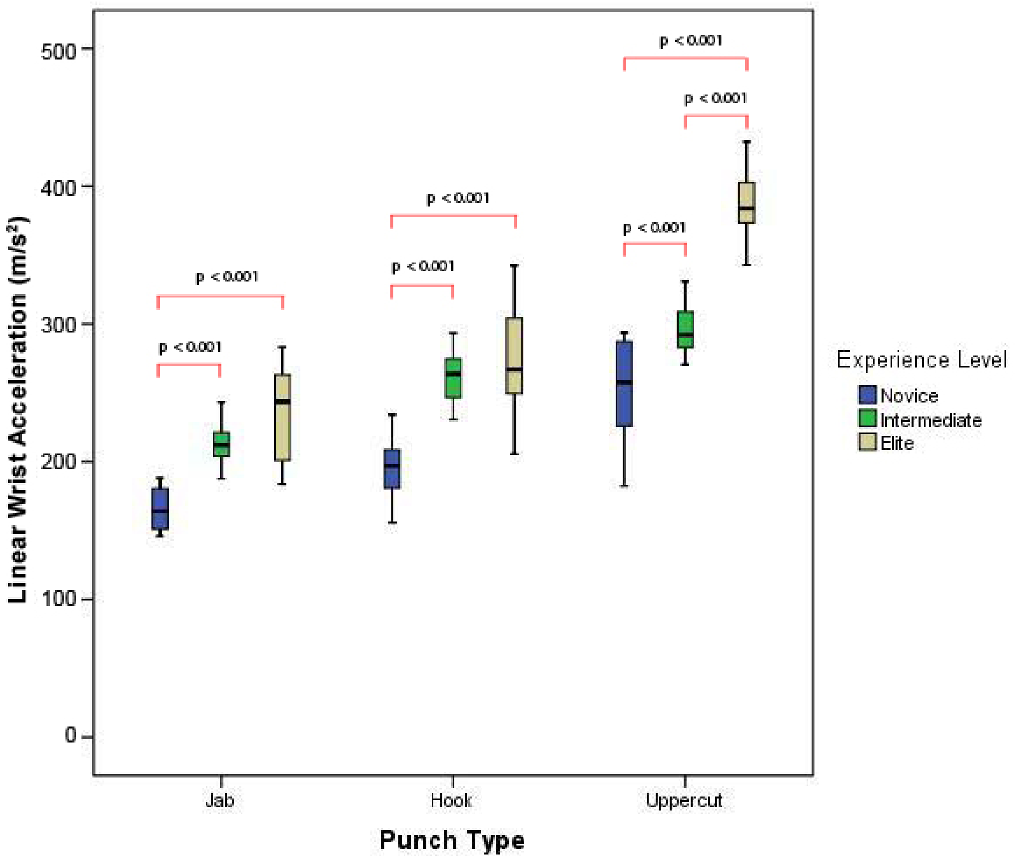


Figure 22. Mean linear wrist acceleration (m/s^2) of the subjects according to the experience level and punch type (p indicates significance level)

Moreover elite level boxers generated larger linear wrist acceleration than that of novice level boxers at the hook and jab punches, and intermediate level boxers also generated larger linear wrist acceleration than that of novice level boxers at the hook and jab punches (Figure 22).

According to the results of post-hoc analysis, the main effect of punch type on linear wrist acceleration was significant, $F(2,81) = 105.0$, $p < 0.001$. The results of analysis showed that the uppercut punch generated larger linear wrist acceleration compared to the hook and jab punch in boxers (Figure 22).

4.4 Translational Hand Acceleration

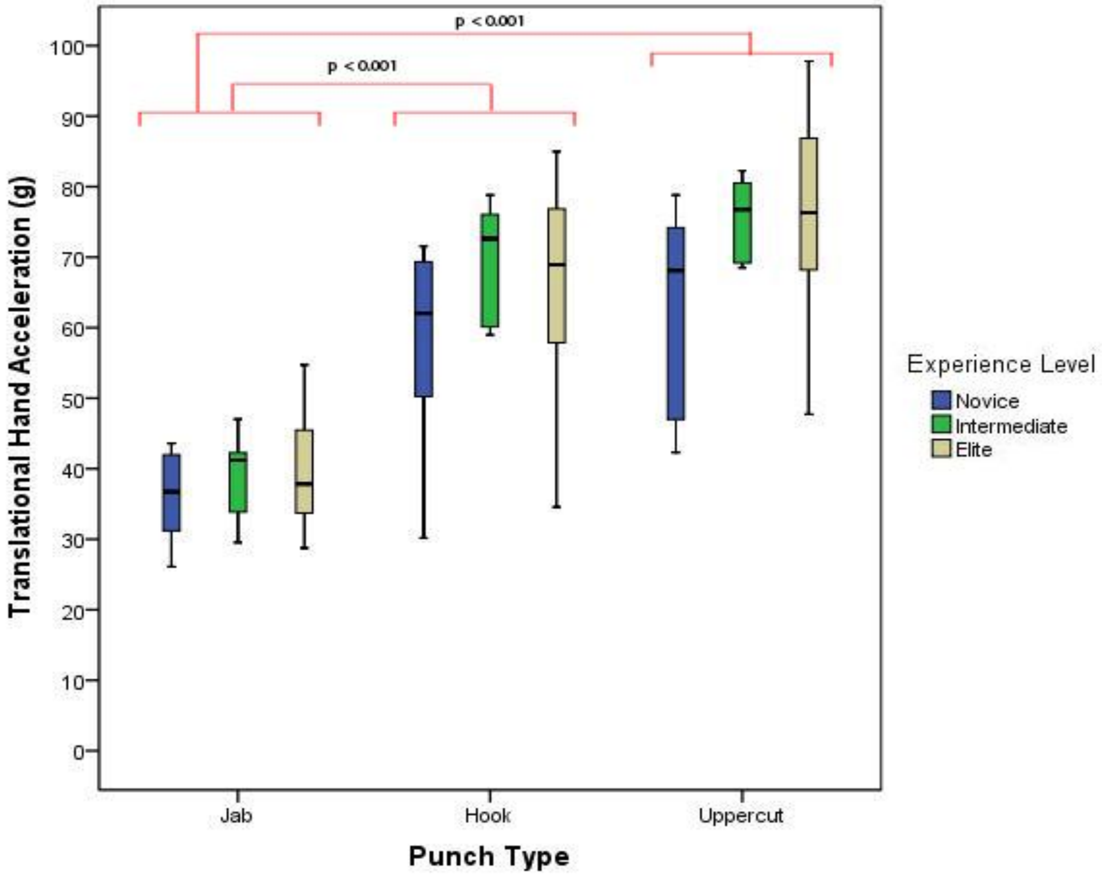


Figure 23. Mean translational hand acceleration (g) of the subjects according to the experience level and punch type (p indicates significance level)

Post-hoc analysis showed that the main effect of experience level on translational hand acceleration was not significant, $F(2,81) = 2.7$, $p = 0.7$. According to the results, elite level boxers did not generate larger translational hand acceleration than that of intermediate and novice level boxers (Figure 23).

On the other hand, according to the results of post-hoc analysis, the main effect of punch type on translational hand acceleration was significant, $F(2,81) = 55.0$, p <

0.001. The results of analysis showed that the uppercut punch generated larger translational hand acceleration compared to the jab punch in boxers. Moreover, the hook punch generated larger translational hand acceleration compared to the jab punch in boxers (Figure 23).

4.5 Vertical GRF

Post-hoc analysis showed that the main effect of experience level on vertical GRF, i.e. in z direction, was not significant, $F(2,81) = 0.7$, $p = 0.5$.

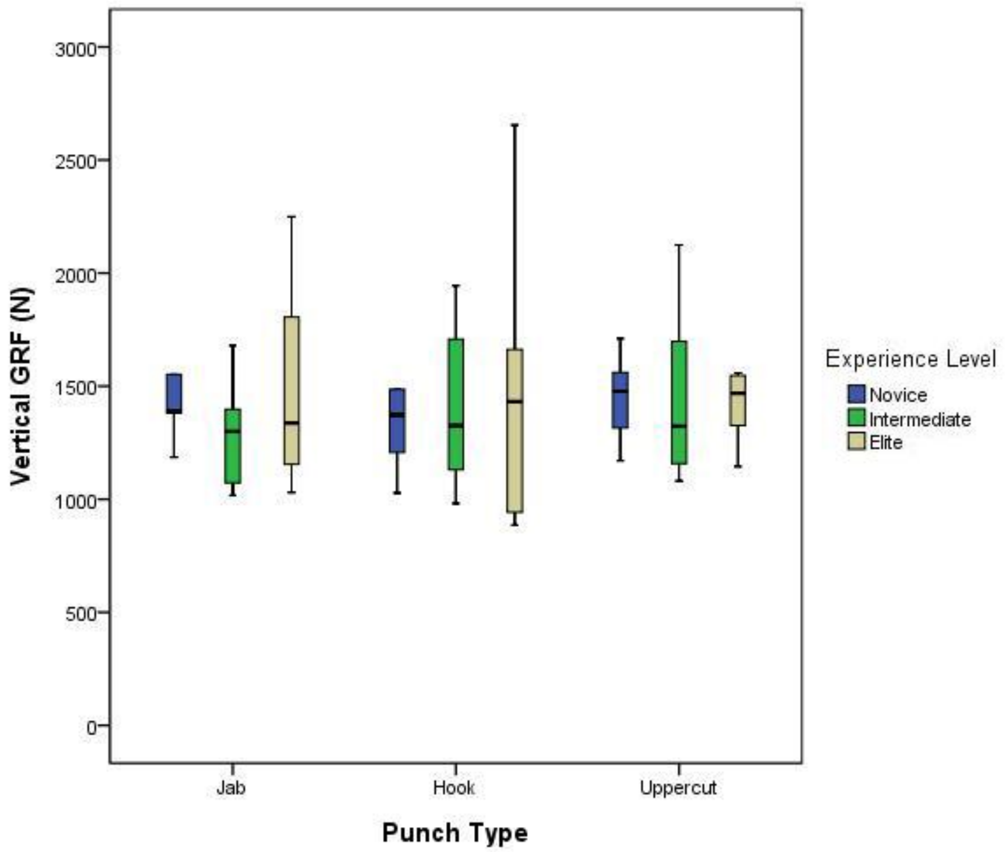


Figure 24. Mean vertical GRF (N) of the subjects according to the experience level and punch type (p indicates significance level)

According to the results, elite level boxers did not generate larger vertical GRF than that of intermediate and novice level boxers (Figure 24).

Similarly, according to the results of post-hoc analysis, the main effect of punch type on vertical GRF was not significant, $F(2,81) = 0.2$, $p = 0.8$. The results of analysis showed that the uppercut punch did not generated larger vertical GRF compared to the hook and jab punch in boxers (Figure 24).

CHAPTER V

DISCUSSION

The ability to deliver punches with effective technique both maximum force and also with speed are important considerations in amateur boxing (Dyson, Smith, Fenn & Martin, 2005). Moreover, determining the kinematic factors that are contribute to a forceful punch is fundamental to the improvement of the techniques of amateur boxers. Therefore, the main objective of this study was to determine differences, if any, in three-dimensional (3D) kinematic characteristics of the three principal punches (the jab, hook and uppercut) executed by novice, intermediate and elite level male amateur boxers. Specifically, the kinematic parameters related to the displacement, linear velocity and linear acceleration of the upper body segments, translational acceleration of the hand, and vertical GRF of the boxers were analyzed as they throwing the three different punches. Therefore, the results of each kinematic measure were discussed separately.

5.1 Discussion of Displacement Data

The results for the effect of experience level on displacement did not support the hypothesis that elite level boxers would generate larger shoulder, elbow and wrist displacement compared to intermediate and novice level boxers. Although, elite level boxers generated larger shoulder displacement than that of intermediate and novice level boxers at the hook punch, they only generated larger shoulder displacement than that of the novice level boxers at the jab punch (Figure 14). Similarly, elite level boxers only generated larger elbow displacement than that of novice level boxers at the jab punch (Figure 15). However, elite level boxers did not generate larger wrist displacement than that of intermediate and novice level boxers at any punch type (Figure 16).

Likewise, the results for the effect of punch type on displacement did not support the hypothesis that the uppercut punch would generate larger shoulder, elbow and wrist displacement compared to the hook and jab punches. Unlike the stated hypothesis, the hook punch generated larger shoulder displacement compared to the jab and uppercut punches. Although there was no significant punch difference on elbow displacement, the jab punch generated larger wrist displacement compared to the uppercut.

This finding is also not consistent with the study of Donivan (1984). According to this study, wrist displacement of the hook punch at novice level boxers was larger than that of the cross and jab punch in Donivan's study. But, it is not possible to compare other displacement variables of the three principal boxing punches presented here to the previous studies. Because, the study of Donivan was the only one that reported wrist displacement data of novice level boxers in the literature. Unfortunately, there was no study was reported shoulder and elbow displacement data in boxers. Therefore, the cause of displacement difference may attribute to the amount of the rearward or preparatory movement of the boxers executing the punches. However, this study did not focus on rearward or preparatory movement of the boxers.

5.2 Discussion of Linear Velocity Data

The results for the effect of experience level on linear velocity did not support the hypothesis that elite level boxers would generate larger linear shoulder, elbow and wrist velocity compared to intermediate and novice level boxers.

Although there was no interaction effect between experience level and punch type, elite level boxers generated larger linear shoulder velocity than that of intermediate and novice level boxers (Figure 17). But, elite level boxers only generated larger linear elbow and wrist velocity than that of the intermediate and novice level boxers at the uppercut punch (Figure 17 and 18). Similarly, elite level boxers only generated larger linear elbow velocity than that of novice level boxers at the jab punch (Figure 17). However, elite level boxers did not generated linear wrist velocity than that of intermediate and novice level boxers at any punch type (Figure 19).

The results of the current study were not consistent with the previous studies regarding the effect of the experience level on linear shoulder velocity. The findings of Whiting, Gregor & Finerman (1988) revealed that linear shoulder velocity of the jab punch at intermediate level boxers was larger than that of this study. But, shoulder velocity of the hook punch reported in the current study was larger than that in the study of Whiting et al. On the other hand, findings of the current study showed that elbow velocity of the jab and hook punch at intermediate level boxers was lower than those of the jab and hook punch in the study of Whiting et al. But, both studies were consistent that there were no significant linear elbow velocity differences between the hook and the jab punches at intermediate level boxers.

According to the study of Chiu & Shiang (1999), linear wrist velocity of the standing jab punch was lower than those in the current study. But, the other linear wrist velocity values of the jab punch in the literature was somewhat higher than that in the current study. Although there was no significant linear wrist velocity differences between the hook and the jab punch in the current study, Whitting, Gregor & Finerman (1988) found that wrist velocity for the hook punch was higher than the jab punch at intermediate level boxers. Moreover, linear wrist velocity of the jab and hook punches in the study of Whitting, Gregor & Finerman were larger than that of the current study. However, according to Donivan (1984), wrist velocity for the hook punch was also higher than the jab punch at novice level boxers.

Similarly, the results for the effect of punch type on linear velocity did not support the hypothesis that the uppercut punch would generate larger linear shoulder, elbow and wrist velocity compared to the hook and jab punches. Unlike the stated hypothesis, the uppercut and hook punch generated larger linear shoulder velocity compared to the jab punch. But, the uppercut punch generated larger linear elbow and wrist velocity compared to the jab punch.

5.3 Discussion of Linear Acceleration Data

The results for the effect of experience level on linear acceleration did not support the hypothesis that elite level boxers would generate larger linear shoulder, elbow and wrist acceleration compared to intermediate and novice level boxers.

Although there was no interaction between experience level and punch type, elite level boxers only generated larger linear shoulder and elbow acceleration than that of intermediate and novice level boxers (Figure 20 and 21). But, elite level boxers only generated larger linear elbow and wrist acceleration than that of the intermediate and novice level boxers at the hook and uppercut punch (Figure 21 and 22). Similarly, elite level boxers only generated larger linear elbow and wrist acceleration than that of novice level boxers at the jab punch (Figure 21 and 22).

Similarly, the results for the effect of punch type on linear acceleration supported the hypothesis that the uppercut punch would generate larger linear shoulder, elbow and wrist acceleration compared to the hook and jab punches. But, the findings of the current study also revealed that linear elbow and wrist acceleration of intermediate level boxers at the jab and hook punches was larger than that of reported in the literature. As a matter of fact, only Whiting, Gregor & Finerman (1988) reported the linear shoulder, elbow and wrist acceleration of four intermediate level boxers at the jab and hook punch and their linear shoulder acceleration results were slightly larger than that of the current study. However, Donivan (1984) reported linear wrist acceleration of nine novice level boxers at the jab and hook punch and his results were also smaller than that of the current study.

In general, kinematic parameters such as the displacement, linear velocity and acceleration reflect the movement pattern in the execution of the punch. These parameters indicate the amount of involvement of the upper torso of the body in the execution of the punch. As described before, the jab, by their direct line of action, is primarily an extension of the arm with the rotation of the shoulder. The hook and uppercut, on the other hand, incorporates not only a rotation of the shoulders, but also the entire trunk. In order to rotate the trunk of the body, it requires the flexing of the knee with an advancing step which allows for a greater rearward movement prior to the forward movement. Furthermore, in order to increase the final linear velocity and acceleration of the hand, the major contribution probably comes from the motion of other body parts such as pivoting of the rear foot, the turning of the hips and trunk, and the position of the arms. Eventhough, the body orientation is not the scope of this study, started to punch in a static position to eliminate different body orientation may be cause for different values of displacement, linear velocity and acceleration than that of in the literature. Therefore, the larger values, in comparison with other studies, may be the result of experimental protocol used in the current study, which is called for isolated maximal punch than the more competition like punches found in other studies. Of course, the logical next step is to investigate punching mechanics during competition with an opponent.

The skill levels of the boxers may be another factor which has contributed to the generation of larger kinematic parameters at impact. The results of the analyses revealed that skill level of the participants had an effect on strategies of motion. Because, novice level boxers has not full motor or movement control over the punches. When velocity and acceleration were analyzed the less skilled boxers were more affected. Even though the sample, as a whole was regarded as a relatively competent group of boxers based upon their past experience, one third of the boxers had not fought any regulation bouts. This could account for the low impact velocity and acceleration because of the inability to judge the temporal relationships at impact that would produce peak velocity at impact and theoretically maximum force. Another reason for the low kinematic parameters may be less amount of weight transfer from rear foot to the lead foot. For the maximum velocity and acceleration in all cases, transfer of weight from the rear foot to the lead foot is crucial. As the boxers started to punch in a static position in the current study, they may not capable of more weight transfer from one foot to another. Moreover, if the boxer's weight is already on the front foot then this may cause a loss in forward propulsion or velocity. One last explanation for the different values of displacement, velocity and acceleration could be the camera placement of the previous studies with respect to the arm movement pattern. However, not all of the movement was in the sagittal plane, some parts were in the transverse plane. Despite the efforts to film the majority of the movement in a field that was perpendicular to the axis of the camera lens, it is conceivable that not all of the important motion was in this plane, i.e. the location where actual peak velocity occurred. This would create errors in measurement which could lead to erroneous results. This is primarily due to the motion of the hook and uppercut punches. Therefore, biomechanical properties of boxing mechanics can be investigated using more sophisticated technological tools.

5.4 Discussion of Translational Hand Acceleration Data

The results of the current study showed that translational hand acceleration at uppercut punch (71 g) was significantly larger than the hook (63.2 g) and jab punch (38.3 g). According to the study of Atha, Yeadon, Sandover & Parsons (1985), a world ranked British professional heavyweight boxer was delivered a straight blow to the pendulum with the acceleration of 53 g. This was higher than the results of the current study. Despite the fact that this result reflected the acceleration of a heavyweight boxer's punch, the model's biofidelity was unknown. Moreover, the only one boxer participated in the study so extrapolations to the general boxing population are not possible.

Smith, Bishop & Wells (1986), on the other hand, evaluated 3 amateur boxers hand acceleration and found that linear acceleration for the left jab and the left hook was 21.5 g and 43.6 g, respectively. Their findings were lower than the current study but it is not possible to compare the findings of their study with the current one. Because, they evaluated only the left jab and the left hook punches unlike the current study.
Walilko et al., (2005) evaluated the jab punch of seven Olympic boxers from five weight classes. They reported peak translational acceleration as 58 g. The findings of their study were higher than the current one.

5.5 Discussion of Vertical GRF

According to the results of the current study, there was no significant differences between experience level and punch type in terms of vertical GRF. Unfortunately, there was no literature on the vertical ground reaction force of boxers as executing the punches. But, the findings of the current study consistent with the Taekwondo study in the literature. According to Park's study (1989), they did not find a significant vertical GRF differences between the three different styles of front kick.

In boxing, boxers take an advance step with push the ground off forcefully to generate and transfer more momentum to the punching hand. For each punch, any difference in the push off action of the rear foot should result in a difference in the vertical ground reaction force. This would cause a difference in the maximum acceleration of the hand at the impact. But, in the current study boxers executed three different punches without taking an advance step. This factor may be important in explaining the cause of any difference found between vertical GRF and translational hand acceleration at three different punch types. Therefore, future studies related with boxing should investigate whether is there any relationship between vertical GRF and translational or rotatonal hand acceleration more detailed.

In summary, results of the study indicated that the type of punch and experience level are the major factors in determining the magnitude of displacement, linear velocity, linear acceleration, and translational hand acceleration parameters.

CHAPTER VI

SUMMARY, CONCLUSIONS & RECOMMENDATIONS

6.1 Summary

Boxing is one of the oldest form of the sports and its popularity has been increased in recent years. Therefore, boxing has been the focus of numerous studies in the literature. With the increasing concern on the safety measurements, most of the studies have investigated the biomechanical assessment of injuries, head impact responses and punch force. But, there is limited work on the factors which makes difference on the generation of force, velocity or acceleration based upon the level of a boxer and punch type.

Therefore, the main objective of this study was to determine differences, if any, in three-dimensional (3D) kinematic characteristics of the three principal punches (the jab, hook and uppercut) executed by novice, intermediate and elite level male amateur boxers. Specifically, the kinematic variables related to the displacement, linear velocity and linear acceleration of the upper body segments, translational hand acceleration and vertical GRF generated by boxers were analyzed as they throwing the three different punches.

The subject of this study composed of 10 Novice, 9 Intermediate, and 11 Elite level amateur boxers. The subject of this study composed of 10 novice, 9 intermediate, and

11 elite level amateur male boxers. Ages of the subjects ranged from 18 to 34 years old.

The anthropometric measurements including height, weight, and width of the segments were measured and recorded from each subject after the Informed Consent Form was signed. After the 5 minutes self-selected warm-up, 38 active LED markers were placed on the anatomically relevant locations of the subjects according to the Helen Hayes marker set. Then, a Static Trial was obtained from the subjects. A ±250g capacity, single axis accelerometer was used to measure translational hand acceleration of the boxers. All subjects stand on a 120x120 cm Bertec Force plate and executed their punches toward a head-high target on a standard practice bag. The motions were captured with PhaseSpace real time optical tracking system with 8 high speed cameras at 240 fps. Then, the motions captured were analyzed to quantify the kinematic parameters associated with each punch by Visual3D Biomechanical Analysis and Modeling Software.

3 x 3 factorial ANOVA design with Tukey HSD post-hoc test were used to see whether the factor effects of the experience level or punch type on the kinematic variables separately. A Pearson Correlations test was also used to analyze descriptive characteristics of subjects and Alpha level was set at $p < 0.05$.

The results showed that elite level boxers generated larger shoulder and elbow displacement than that of novice level boxers at the jab punch. Moreover, elite level boxers generated larger shoulder displacement than that of intermediate and novice level boxers at the hook punch. The jab punch also generated larger shoulder and wrist displacement compared to the uppercut punch.

Although elite level boxers generated larger linear shoulder velocity than that of intermediate and novice level boxers, the uppercut and hook punches generated larger linear shoulder velocity compared to the jab punch. Elite level boxers generated larger elbow and wrist velocity than that of intermediate and novice level boxers at the uppercut punch. Moreover, elite level boxers also generated larger linear elbow velocity than that of novice level boxers at the jab punch. But, the uppercut punch generated larger elbow and wrist velocity compared to the jab punch.

Similarly, elite level boxers generated larger linear shoulder acceleration than that of intermediate and novice level boxers. But, the uppercut punch generated larger linear shoulder, elbow and wrist acceleration compared to the hook and jab punches. Moreover, elite level boxers also generated larger linear elbow and wrist acceleration than that of novice level boxers at the jab punch. Likewise, elite level boxers generated larger linear elbow and wrist acceleration than that of intermediate and novice level boxers at the hook and uppercut punches.

Although, the uppercut and hook punches generated larger translational hand acceleration compared to the jab punch, elite level boxers did not generate larger vertical GRF than that of intermediate and novice level boxers. Moreover, the uppercut punch did not generate larger vertical GRF compared to the hook and jab punch in boxers.

Finally, the results for all kinematic variables demonstrated that the type of punch executed and experience level of the boxers were the major determinant of the magnitude of each factor studied.

6.2 Conclusions

This study concluded that the jab punch also generated larger shoulder and wrist velocity compared to the uppercut punch. Moreover, elite level boxers generated larger shoulder and elbow displacement than that of novice level boxers at the jab punch.

However, the uppercut punch also generated larger shoulder, elbow and wrist velocity compared to the jab punch; elite level boxers generated larger linear elbow and wrist velocity than that of intermediate and novice level boxers at uppercut punch.

Likewise, the uppercut punch generated larger shoulder, elbow and wrist acceleration compared to the hook and jab punches. Although, elite level boxers generated larger linear elbow and wrist acceleration than that of intermediate and novice level boxers at uppercut and jab punches.

Moreover, the uppercut and hook punches generated larger translational hand acceleration compared to the jab.

Finally, elite level boxers did not generate larger vertical GRF than that of intermediate and novice level boxers. Additionally, the uppercut punch did not generate larger vertical GRF compared to the hook and jab punch in boxers

As a conclusion, results of the study concluded that the type of punch and experience level of the boxers were the major factors in determining the magnitude of displacement, linear velocity, linear acceleration, and translational hand acceleration parameters.

6.3 Recommendations

Based on the results of this study, following recommendation for future research can be made.

1. The influence of the foot, leg, hip and specially the trunk movement in the generation of velocity and acceleration should be studied more detailed.
2. Future work should also investigate GRFs of the lead and rear foot, and displacement of the center of mass.
3. Boxers should concentrate on developing the hand speed immediately before the impact.
4. Further studies could investigate the effectiveness of training methods for developing velocity and acceleration of the hand to increase punch force.
5. Practitioners may consider trying to increase their lean body mass if they wish to increase the impact force of their punch, so long as this does not

result in a reduced speed of the punch. It must be remembered that agility may be compromised by weight gains.

6. The punching mechanics during competition with an opponent may be investigated, either in a sparring session or during an actual bout.

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APPENDICES

A. Bilgilendirilmiş Gönüllü Olur Formu

BİLGİLENDİRİLMİŞ GÖNÜLLÜ OLUR FORMU

Boksta 3 farklı vuruş tekniğinin biyomekaniksel olarak incelenmesi ile ilgili yeni bir araştırma yapmaktayız. Araştırmanın ismi "Amatör bokstaki 3 farklı yumruğun 3 boyutlu kinematik analizi"dir. Sizin de bu araştırmaya katılmanızı öneriyoruz. Çünkü bu araştırma sonunda 3 farklı yumruk tekniğiniz incelenecek, analizi yapılacak ve gerekli bilgiler tarafınıza bildirilecektir. Ancak hemen söyleyelim ki bu araştırmaya katılıp katılmamakta serbestsiniz. Çalışmaya katılım gönüllülük esasına dayalıdır. Kararınızdan önce araştırma hakkında sizi bilgilendirmek istiyoruz. Bu bilgileri okuyup anladıktan sonra araştırmaya katılmak isterseniz formu imzalayınız.

Bu araştırmayı yapmak istememizin nedeni, 3 boyutlu hareket analizi yöntemi kullanarak Boksta ki 3 temel yumruğu (direk, kroşe, aparkat) incelemek ve boksörlerin yumruk atarken nasıl bir strateji izlediklerini, üst ektremitedeki omuz, dirsek ve elbileğinin yerdeğitirmesini, doğrusal hızlarını ve ivmelerini, elin doğrusal ivmesini ve dikey yer tepki kuvvetlerini araştırmaktır. Hareket analizini yaparken herbiri saniyede 240 kare fotoğraf çekebilen 8 tane yüksek hızlı kamera kullanacağız. Eklem hareketlerini takip edebilmek için ayakbileği, diz, kalça, omuz, dirsek, elbileği eklemlerinize ve uzuvlarınızdaki bazı noktalara çift taraflı bant ile kameraların algılayabileceği led işaretleyiciler yapıştıracağız

Daha sonra kum torbasına, 3 farklı yumruk atmanızı isteyeceğiz ve bu vuruşları filme alacağız. Yumruk atarken yere uyguladığınız kuvvetleri analiz edebilmek için yumruklarınızı 1.20 x 1.20 m. boyutlarında özel yapım kuvvet platformu üzerinde yapacaksınız. Ayrıca vuruş yaptığınız elin avuç içine ±200 g kapasiteli mems tabanlı tek yönlü ivme ölçer yerleştirilecek ve attığınız yumrukların ivmelerini ölçeceğiz. Kaydettiğimiz bu görüntüleri bilgisayardaki özel bir yazılımla inceleyerek yumruk atarken nasıl davrandığınızı ve ne gibi stratejiler kullandığınızı ortaya çıkarmış olacağız. Kullanılacak bu aletlerin vücudunuza veya sağlığınıza herhangi bir zararlı etkisi yoktur. Sadece bantları sökerken canınız birazcık yanabilir ve deriniz de de kızarıklık oluşabilir. Ama bu etkilerde kısa sürede geçecektir.

ODTÜ Beden Eğitimi ve Spor Bölümünde yaptığım doktora tezim için bu çalışmaya katılımınız araştırmanın başarısı için önemlidir. Eğer araştırmaya katılmayı kabul ederseniz araştırmacı Serkan DÜZ tarafından boy, kilo, kol, bacak uzunlukları ve çevre ölçümleri gibi bazı vücut parametreleriniz ölçülecektir. Bu çalışmaya katılmanız için sizden herhangi bir ücret istenmeyecektir. Çalışmaya katıldığınız için size ek bir ödeme de yapılmayacaktır.

Bu çalışmaya katılmayı reddedebilirsiniz. Bu araştırmaya katılmak tamamen isteğe bağlıdır ve reddettiğiniz takdirde herhangi bir zarar görmeyeceksiniz. Yine çalışmanın herhangi bir aşamasında onayınızı çekmek hakkına da sahipsiniz. Çalışma hakkında daha fazla bilgi almak için ODTÜ Beden Eğitimi Bölümü öğretim üyelerinden Prof. Dr. Feza KORKUSUZ (Tel: 210 4950; e-posta: feza@metu.edu.tr) ya da araştırmacı Serkan DÜZ (Tel: 2104016; e-posta: serkanduz@yahoo.com) ile iletişim kurabilirsiniz.

(Katılımcı Beyanı)

Araştırmacı Serkan DÜZ, ODTÜ T.S.K. Modelleme ve Simülasyon Araştırma ve Uygulama Merkezi Mo-Cap hareket yakalama laboratuvarıda, Boks'ta ki 3 temel vuruşun kinematik analizi için biyomekaniksel bir araştırma yapacaklarını belirtilerek bu araştırma ile ilgili yukarıdaki bilgileri bana aktardı. Bu bilgilerden sonra böyle bir araştırmaya "katılımcı" (denek) olarak davet edildim.

Eğer bu araştırmaya katılırsam araştırmacı ile aramda kalması gereken bana ait bilgilerin gizliliğine araştırma sırasında ve sonrasında büyük bir özen ve saygı gösterileceğine inanıyorum. Araştırma sonuçlarının eğitim ve bilimsel amaçlarla kullanımı sırasında da kişisel bilgilerimin ihtimamla korunacağı konusunda bana yeterli güven verildi.

Projenin yürütülmesi sırasında herhangi bir sebep göstermeden araştırmadan çekilebilirim. (Ancak araştırmacıları zor durumda bırakmamak için araştırmadan çekileceğimi önceden bildirmemim uygun olacağının bilincindeyim*)* Ayrıca herhangi bir zarar verilmemesi koşuluyla araştırmacı tarafından araştırma dışı tutulabilirim. Araştırma için yapılacak harcamalarla ilgili herhangi bir parasal sorumluluk altına girmiyorum. Bana da bir ödeme yapılmayacaktır.

İster doğrudan, ister dolaylı olsun araştırma uygulamasından kaynaklanan nedenlerle meydana gelebilecek herhangi bir sağlık sorunumun ortaya çıkması halinde, her türlü tıbbi müdahalenin sağlanacağı konusunda tarafıma gerekli güvence verildi.

Bu araştırmaya katılmak zorunda değilim ve katılmayabilirim. Araştırmaya katılmam konusunda zorlayıcı bir davranışla karşılaşmış da değilim. Eğer katılmayı reddedersem, bu durumun bana ve araştırmacı ile olan ilişkime herhangi bir zarar getirmeyeceğini de biliyorum.

Bana yapılan tüm açıklamaları ayrıntılarıyla anlamış bulunmaktayım. Kendi başıma belli bir düşünme süresi sonunda adı geçen bu araştırma projesinde "katılımcı" (denek) olarak yer alma kararını aldım. Bu konuda yapılan daveti büyük bir memnuniyet ve gönüllülük içerisinde kabul ediyorum.

İmzalı bu formun bir kopyası bana verilecektir.

Katılımcının

Adı, Soyadı:

Tel :

İmza :

Görüşme tanığının

Adı, Soyadı :

Adres :

Tel :

İmza :

Katılımcı ile görüşen araştırmacının

Adı Soyadı, ünvanı :

Adres :

Tel :

İmza :

B. Record sheet of the antropometric measurements and body segment parameters of the subject

Subject ID :

Birth Date :

Weight :

Height :

Foot Length (MTA) :

Ankle Radius :

Knee Radius :

Hip width :

Pelvis Depth :

Elbow Radius :

Trunk Depth :

Shoulder Radius :

Shoulder With :

Wrist Radius :

C. Curriculum Vitae

PERSONAL INFORMATION

Surname, Name	: Düz, Serkan
Nationality	: Turkish (TC)
Date of Birth	: 9 April 1976
Place of Birth	: Yeşilyurt/ MALATYA
Marital Status	: Married
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CONTACT INFORMATION

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EDUCATION DETAILS

Degree	Institution	Year of Graduation
MS	METU – Physical Education and Sports Department	2003
BS	METU – Physical Education and Sports Department	2001
High School	Malatya High School, MALATYA	1993

WORK EXPERIENCE

Year	Place	Enrollment
2003- Present	Ministry of National Education	Physical Education Teacher

FOREIGN LANGUAGES

Advanced English, Beginner Spanish

RESEARCH INTEREST

Physiology of Exercise
Sports Nutrition
Sports Biomechanics

PUBLICATIONS

International Publications:

Düz, S., Koçak, M. S., & Korkusuz, F. (2009). Evaluation of body composition using three different methods compared to dual-energy X-ray absorptiometry. *European Journal of Sport Science*, 9, 181-190.

Özdurak, R.H., **Düz, S.,** Arsal, G., Akıncı, Y., Kablan, N., Işıklı, S., & Korkusuz, F. (2003). Quantitative forearm muscle strength influences radial bone mineral density in osteoporotic and healthy males. *Technology and Healthcare*, 11, p.253-261.

International Congress and Presentations:

Düz, S., Koçak, S., & Korkusuz, F. (2008). Evaluation of body composition using three different methods compared to dexa in Turkish university students. Paper presented at the *European College of Sport Science (ECSS)*, Estoril, Portugal, p. 695.

Düz, S., Koçak, S., & Korkusuz, F. (2005). Effects of obesity on lipoprotein profiles in nondiabetic Turkish university students. *46th ICHPER.SD Aniversary World Congress*, İstanbul, p. 432-434. Poster presentation.

Özdurak, R.H., **Düz, S**, Arsal, G, Akıncı, Y, Kablan, N, Işıklı, S, & Korkusuz, F. (2002). Muscle and grip strength in forearms and their relation to radial bone mineral density. *7th International Sport Sciences* Congress, Antalya, Turkey, p. 214. Poster presentation.

Tümer, İ., Çolak, R., **Düz, S.,** & Arıtan, S. (2002). Dikey sıçramanın iki boyutlu biyomekaniksel modellenmesi. *7th International Sport Sciences* Congress, Antalya, Türkiye, Oral presentation.

HOBBIES

Boxing, Scuba Diving, Fitness Training, Computer Technologies, Movies, & Motor Sports.

D. Türkçe Özet

AMATÖR BOKSTA 3 FARKLI YUMRUĞUN 3 BOYUTLU KİNEMATİK ANALİZİ

GİRİŞ

Dünyadaki en eski sporlardan birisi olan boksun popülaritesi son yıllarda dünyada olduğu gibi ülkemizde de gün geçtikçe artmaktadır. Hatta Türkiye deki amatör boksör sayısında ki hızlı artış uluslarası amatör boks birliğinin internet sayfasından "Mersin de yapılan Türkiye erkekler boks şampiyonası 2010 yılında avrupa daki en büyük katılımlı organizasyon olmuştur" şeklinde yayımlanmıştır.

Boks aslında rakibe karşı gard, savunma ve atak yapmak için birçok beceri ve tekniğin birarada kullanıldığı dövüş sporlarından birisidir. Bokstaki asıl amaç rakibin yumruklarından sakınarak rakibine yumruk atmaktır ve kazanmayı kesinleştirmek için rakibi nakavt etmektir (Mack, Stojsih, Sherman, Dau ve Bir, 2010). Boks dayanıklılık, kuvvet, çabukluk, koordinasyon ve hızın bir arada olduğu bir dövüş sporu olduğundan, boksörler fiziksel ve mental olarak bu spora hazır olmalıdırlar (Smith, Dyson, Hale ve Janaway 2000; Mack, Stojsih, Sherman, Dau ve Bir, 2010).

Boks sporu profesyonel ve amatör olarak ikiye ayrılır. Her iki şekilde de boksörler eldiven giyerek rakibe karşı sadece yumruklarıyla atak ve savunma yaparlar. Her raunt genellikle 3 dakika sürer ve raunt aralarda 1 dakikalık dinlenme zamanı vardır. Kazanan en fazla temiz ve net yumruk atan veya rakibini nakavt eden boksör olur. Fakat amatör boks profesyonel bokstan amaç, motivasyon, kurallar, puanlamalar ve ekipman olarak çok farklı ve daha güvenlidir (Hahn ve arkadaşları, 2010). Ayrıca, amatör boskta sporcuların darbeleri absorbe eden kask, içi süngerden yapılmış eldivenler, şort ve farklı renklerde kısa kollu tişört giymesi zorunluyken profesyonel boksta sporcular sadece şort giyer ve vücutlarının üst kısmı çıplak olarak kask takmadan dövüşürler. Amatör boksta puanlama yumruğun ne kadar kuvvetli atıldığına veya verdiği hasara göre değil de yumruğun açık ve net olmasına göre yapılır. Rakibi nakavt edebilecek çok kuvvetli bir yumruk ile temiz ve net bir yumruk aynı puanı alır. Amatör boskta nerdeyse hiç nakavt olmaz, bu yüzden amaç profesyonel boksun tersine rakibi nakavt etmek değil, olabildiğince temiz ve net yumruk atarak puan almaktır (AIBA teknik ve yarışma kuralları, 2010). Fakat profesyonel boks bir meslektir ve asıl amaç para kazanmaktır. Bu yüzden profesyonel boksörler nakavt için özendirilirler ve rakibini yere indirdiği her raunt için fazladan puan alırlar. Profesyonel boksörler uzun kariyerleri boyunca amatör boksörlerden daha sık ve daha kuvvetli yumruklara maruz kaldıklarından yaralanmaları da son derece ciddidir. Daha da önemlisi profesyonel boksörler şiddetli kafa darbelerine ve beyin hasarı riskine maruz kalırlar (Gartland, Malik, & Lowell, 2001). Bu yüzden özellikle gençler ve üniversiteliler arasında, hem erkek hem de bayanlar da, amatör boksa katılım hızla popüler olmaktadır.

Boks popüleritesine rağmen her zaman bir çok tartışmanın kaynağı olmuştur. Çünkü boksun doğası gereği kuvvetli ve arka arkaya yenen yumruklar maç esnasında veya sonrasında boksörlerde ciddi beyin yada kafa travmaları riski oluşturmaktadır (Unterhamscheidt, 1995; Ross ve Ochsner, 1999). Bu yüzden boks sporu 30 yıldan fazla zamandır akut ve kronik travmatik beyin hasarları bakımından araştırılmaktadır. Aslında boks sporu birçok tehlikeler içermesine rağmen sporun faydaları negatif yönlerinden daha ağır basıyor. Boksun sadece fiziksel değil aynı zamanda psikolojik faydaları da vardır (Piau, 1965). Örneğin, mental disiplini geliştirir, agresif davranışları ortadan kaldırır, kendine güvensizlik ve yetersizlik gibi duyguları ortadan kaldırır (Parker ve Trifunov, 1960). Bu yüzden daha iyi gözlem, boksörlerin yıllık müsabaka sayısının azaltılması ve diğer güvenlik önlemlerinin artırılması ile sakatlıkların sıklığı ve şiddeti azaltılabilir (Bledsoe, Li ve Levy, 2005; Unterharnscheidt, 1970). Boksun bu olumsuz etkilerini azaltmak için mutlaka kafanın maruz kaldığı kuvetler ve boksla ilgili biyomekaniksel çalışmalar gereklidir.

Fakat ilginçtir ki literatürde bokstaki yumrukların özellikleriyle ilgili biyomekaniksel çalışmalar kısıtlıdır. Biliyoruz ki, bir yumruğum kuvveti, elin kütlesine ve ivmesine bağlıdır. Fakat, yumruk atan elin kütlesini doğru olarak hesaplamak problemli bir iştir. Çünkü elin kütlesine eldiven, önkol, üstkol, hatta belli bir noktaya kadar gövdenin de etkisi olmaktadır. Bu nedenle ele etkiyen toplam kuvvet boksörün tekniğine ve vücut ağırlığının ne kadarını eline aktardığına göre değişir. Ayrıca, hız veya kuvvet oluşumunda boksörün deneyiminin nasıl fark yarattığı bilinmemektedir. Bu konuda çok az çalışma yapılmıştır. Dolayısı ile bokstaki 3 temel yumruğun mekanik özelliklerini anlamak için; atılan yumruğun yerdeğiştirmesi, hızı ve ivmesinin araştırılması, farklı yumruk tiplerinde ortaya çıkan kuvvetlerin hesaplanmasında yardımcı olabilir.

Bu yüzden, bu çalışmanın amacı amatör boksta eğer varsa başlangıç, orta ve üst düzey boksörler tarafından atılan üç temel yumruğun (direk, kroşe ve aparkat) 3 boyutlu kinematik özelliklerini belirlemektir.Özellikle, boksörlerin üç farklı yumruğu atarken vücütlarının üst kısımlarındaki uzuvlarınn yerdeğiştirmesi, doğrusal hızı ve doğrusal ivmesi, elin doğrusal ivmesi ve dikey yer tepki kuvvetleri gibi kinematik değişkenler analiz edilmiştir

MATERYAL VE METHOD

Örneklem

Bu çalışmaya 10 başlangıç, 9 orta ve 11 adet de üst düzey amatör erkek boksör katılmıştır. Deneklerin yaşı 18 ile 34 arasında değişmektedir. Boksörlerin boks geçmişleri 1 yıl ile 14 yıl arasında değişmektedir. Çalışmaya sadece sağ gardlı boksörler dahil edilmiştir. Her boksörün boyu, ağırlığı ve vücudun bazı bölümlerinin genişliği gibi antropometrik ölçümleri, bilgilendirilmiş gönüllü olur formu imzaladıktan sonra ölçülmüş ve kaydedilmiştir.

Veri Toplama Yöntemi

Boksörlerin boyu duvara monteli dikey cetvel ile, ağırlıkları dijital tartı ile, bazı vücut bölümlerinin genişlikleri ise Vernier marka kaliper ile ölçülmüştür. Her boksör kendi seçtiği 5 dakikalık ısınma hareketlerini yapmasından sonra vucüdundaki ilgili anatomik noktalara Helen Hayes işaretleyici düzenine gore 38 adet aktif led işaretleyici yerleştirilmiştir. Sonra, deneğin sabit bir deneme duruşu kaydedilmiştir. Daha sonra boksörlerin elinin doğrusal ivmesini ölçmek için avuçlarının içerisine ±250 g kapasiteli tek yönlü bir ivme ölçer yerleştirilmiş ve el bandajı ile sabitlenmiştir. Tüm denekler 120x120 cm boyutunda ki özel yapım Bertec marka kuvvet platformu üzerinde durmuş ve standart bir kum torbası üzerindeki baş hizasında duran bir hedefe doğru yumruk atmışlardır. Hareketler 8 adet yüksek hızlı kamera ile saniyede 240 kare fotoğraf çekebilen PhaseSpace gerçek zamanlı optik hareket yakalama sistemi ile kaydedilmiştir. Sonra, kaydedilen hareket bilgileri her bir yumrukla ilgili kinematik değişkenleri sayısallaştırmak için Visual3D biyomekanik analiz ve modelleme programı kullanılarak analiz edilmiştir.

Verilerin Analizi

Kinematik değişkenler üzerinde deneyim düzeyinin mi yoksa yumruk tipinin mi etkili olduğunu anlamak için 3 X 3 faktörlü ANOVA tasarımı ve Tukey HSD post-hoc testi kullanılmıştır. Aynı zamanda deneklerin tanımlayıcı özelliklerini analiz etmek için Pearson korelasyon testi kullanılmış ve alfa seviyesi $p<0.05$ olarak alınmıştır.

BULGULAR

Sonuçlar üst düzey boksörlerin direk yumrukta başlangıç düzey boksörlerden daha büyük omuz ve dirsek yerdeğiştirmeleri ortaya çıkardığını göstermiştir. Ayrıca, üst düzey boksörler, kroşe yumrukta orta ve başlangıç düzey boksörlerden daha büyük omuz yerdeğiştirmesi ortaya çıkarmıştır. Aynı zamanda direk yumruk aparkat yumrukla karşılaştırıldığında daha büyük dirsek yerdeğiştirmesi ortaya çıkarmıştır.

Üst düzey boksörler, orta ve başlangıç düzey boksörlerden daha büyük doğrusal omuz hızları ortaya çıkarmasına rağmen aparkat ve kroşe, direk yumrukla karşılaştırıldığında daha büyük doğrusal omuz hızları ortaya çıkarmıştır.

Üst düzey boksörler, aparkat yumrukta orta ve başlangıç düzey boksörlerden daha büyük doğrusal dirsek ve elbileği hızı ortaya çıkarmıştır. Ayrıca, üst düzey boksörler, direk yumrukta başlangıç düzey boksörlerden daha büyük doğrusal elbileği hızı ortaya çıkarmıştır. Fakat, aparkat yumruk direk yumrukla karşılaştırıldığında daha büyük doğrusal dirsek ve elbileği hızları ortaya çıkarmıştır.

Aynı şekilde, üst düzey boksörler aparkat yumrukta, orta ve başlangıç düzey boksörlerden daha büyük doğrusal dirsek ve elbileği ivmeleri ortaya çıkarmıştır. Fakat, aparkat yumruk, kroşe ve direk yumrukla karşılaştırıldığında daha büyük doğrusal omuz, dirsek ve elbileği ivmeleri ortaya çıkarmıştır. Ayrıca, üst düzey boksörler direk yumrukta, orta ve başlangıç düzey boksörlerden daha büyük doğrusal dirsek ve elbileği ivmeleri ortaya çıkarmıştır. Aynı şekilde, üst düzey boksörler kroşe ve aparkat yumrukta, orta ve başlangıç düzey boksörlerden daha büyük doğrusal dirsek ve elbileği ivmeleri ortaya çıkarmıştır.

Aparkat ve kroşe yumruk direk yumrukla karşılaştırıldığında daha büyük doğrusal el ivmesi ortaya çıkarmasına rağmen, üst düzey boksörler, orta ve başlangıç düzey boksörlerden daha büyük dikey yer tepki kuvvetleri ortaya çıkaramamışlardır. Ayrıca, aparkat yumruk, kroşe ve direk yumrukla karşılaştırıldığında daha büyük dikey yer tepki kuvveti oluşturamamıştır.

Sonuç olarak, tüm kinematik değişkenlerin sonuçları atılan yumruğun tipinin ilgilenilen değişkenin büyüklüğünü belirlemede en büyük unsur olduğunu göstermiştir.

TARTIŞMA VE ÖNERİLER

Yerdeğiştirme Verisinin Tartışması

Deneyim düzeyine göre bakıldığında bu çalışmanın sonuçları, üst düzey boksörlerin orta ve başlangıç düzey boksörlerle karşılaştırıldığında, daha büyük omuz, dirsek ve elbileği yerdeğiştirmesi ortaya çıkaracağı hipotezini destekelememiştir. Bu bulgular Donivan (1984)'ın çalışmasıyla da uyuşmamaktadır. Donivan'a göre başlangıç düzey boksörlerde kroşe yumruk, direk yumruktan daha fazla elbileği yerdeğiştirmesi ortaya çıkarmıştır. Zaten literatürü incelediğimiz de, sadece Donivan'ın başlangıç düzey boksörlerlerin direk ve kroşe yumrukta elbileğinin yerdeğiştirmesi, hızı ve ivmesini incelediğini gördük. Dolayısıyla onun çalışmasıyla bu çalışmanın diğer yerdeğiştirme değişkenlerini kıyaslamak mümkün değildi. Fakat, boksörlerin deneyim düzeyi ve yumruk tipi arasındaki bu yerdeğiştirme farlılıklarının sebebi boksörlerin hareketi yapmadan önceki hazırlanış veya geriye doğru yönelme hareketlerine yorulabilir. Ne var ki, bu çalışmada bunlar incelenmemiştir.

Hız Verisinin Tartışması

Bu çalışmanın sonuçları, üst düzey boksörlerin deneyim düzeyi göre orta ve başlangıç düzey boksörlerle karşılaştırıldığında daha büyük doğrusal omuz, dirsek ve elbileği hızı ortaya çıkaracağı hipotezini desteklenmemiştir. Whiting, Gregor ve Finerman (1988)'nın çalışmasına göre orta düzey boksörlerde direk yumruğun doğrusal omuz hızı bu çalışmadan daha büyük çıkmıştır. Fakat, kroşe yumruğun doğrusal omuz hızı bu çalışmadan daha düşük çıkmıştır. Diğer yandan direk ve kroşe yumrukta dirseğin doğrusal hızı bu çalışmadan daha büyük çıkmıştır. Fakat, her iki çalışma da orta düzey boksörlerde direk ve kroşe yumruk arasında önemli bir doğrusal dirsek hızı farkı bulamamıştır.

Chiu ve Shiang (1999) 'nın çalışmasına göre ise, direk yumruğun doğrusal elbileği hızı bu çalışmadan daha düşük çıkmıştır. Bu çalışmada direk ile kroşe yumruk arasında anlamlı bir fark bulunamasa da, Whitting, Gregor ve Finerman (1988) orta düzey boksörlerde, Donivan (1984) ise başlangıç düzey boksörlerde direk ile kroşe yumruk arasında anlamlı farklar bulmuşlardır.

Aynı şekilde yumruk tipine göre bakıldığında bu çalışmanın sonuçları, aparkat yumruğun, direk ve kroşe yumrukla karşılaştırıldığında daha büyük doğrusal omuz, dirsek ve el bileği hızı ortaya çıkaracağı hipotezini desteklememiştir. Ortaya atılan hipotezin aksine, aparkat ve kroşe yumruk, direk yumruktan daha büyük doğrusal omuz hızı ortaya çıkarmışlardır.

İvme Verisinin Tartışması

Bu çalışmanın sonuçları, üst düzey boksörlerin orta ve başlangıç düzey boksörlerle deneyim düzeyine göre karşılaştırıldığında, daha büyük doğrusal omuz, dirsek ve elbileği ivmesi ortaya çıkaracağı hipotezini desteklememiştir. Fakat, yumruk tipine göre bakıldığında, bu çalışmanın sonuçları, aparkat yumruğun, direk ve kroşe yumruktan daha büyük bir doğrusal omuz, dirsek ve el bileği ivmesi ortaya çıkaracağı hipotezini desteklemiştir. Aslında Whiting, Gregor ve Finerman (1988) sadece 4 tane orta seviye boksörün direk ve kroşe yumrularının doğrusal omuz, dirsek ve elbileği ivmelerini rapor etse de, onların hesapladıkları doğrusal omuz ivmesi bu çalışmadan daha yüksekti. Fakat, Donivan (1984)'ın 9 adet başlangıç düzey boksörler üzerinde yaptığı çalışmanın da sonuçları da doğrusal elbileği ivmeleri açısından bu çalışmanın değerlerinden düşüktü.

Genel olarak yer değiştirme, doğrusal hız ve ivme gibi kinematik değişkenler atılan yumruğun hareket desenini yansıtır. Bu değişkenler yumruk atılırken vücudun üst kısmının ne kadar katıldığını gösterir. Aslında, direk yumruk kolun ileriye doğru omuzdan çevrilerek uzatılmasıyla atılır. Kroşe ve aparkat ise sadece omuzun değil gövdenin de çevrilmesiyle atılır. Tabiki gövdeyi çevirmek için adım atarak dizi de çevirmek gerekir ki bu da ileri doğru hareket etmeden once geriye doğru daha fazla hareket etmeye neden olur. Ayrıca, son hızı ve ivmeyi arttırmak için arkadaki ayağın, kalçanın ve gövdenin dönüşü ve kolların pozisyonu da çok önemli rol oynar. Vücudun rotasyonunu incelemek bu çalışmanın amaçları arasında olmamasına rağmen boksörlerin adım atmadan sabit durarak yumruk atmaları bu çalışmanın sonuçlarının diğer çalışmalardan farklı çıkmasına neden olmuş olabilir.

Ayrıca boksörlerin deneyim düzeyleri kinematik değişkenleri etkileyen başka bir faktör olabilir. Çünkü deneyim düzeyi yumruk atarken uygulanan stratejileri etkiler. Örneğin, başlangıç düzey boksörler yumruklar üzerinde tam bir hareket ve denetim kontrolü sağlayamayabilirler. Bu da başlangıç düzey boksörlerin maksimum kuvvetle yumruk atabilmeleri için uygun vuruş anını ve hızı kestirememelerine ve dolayısıyla hızda ve ivmede düşüşe sebep olur. Bu çalışmadaki kinematik değişkenlerin diğer çalışmalarla farklı çıkmasının başka bir nedeni de arka ayaktan başlayarak ön tarafa yeterli ağırlık aktarımının yapılamaması olabilir. Çünkü bu çalışmada boksörler adım atmadan yerlerinde sabit durarak yumruk atmışlardır. Bu da diğer çalışmalardan farklı kinematik değişkenlerin ortaya çıkmasına sebep olmuş olabilir. Ayrıca yumruk atan boksörün duruşu yanlış ise yani vücut ağırlığı zaten ön ayağı üzerinde ise bu da ileri doğru hızlanmada kayıp yaşatacaktır. Bu çalışmanın sonuçlarının diğer çalışmalardan farklı olmasının son bir açıklaması da önceki çalışmalardaki kamera pozisyonları olabilir. Çünkü hareketlerin çoğu kamerayla aynı düzlemde olsa da bazı bölümleri diğer düzlemlerde gerçekleşir. Bu da ölçümlerde özellikle kroşe ve aparkat yumrukta hatalı sonuçlara sebep olabilir.

Elin Doğrusal İvmesinin Tartışması

Bu çalışmanın sonuçlarına göre aparkat yumruk elin doğrusal ivmesi açısından kroşe ve direk yumruğa göre daha büyük değerler ortaya çıkarmştır. Atha, Yeadon, Sandover ve Parsons (1985)'a göre dünya ağırsiklet boks şampiyonu bir boksörün direk yumruğu sarkacı 53 g ivmesiyle hareket ettirmiştir. Bu değer bu çalışmanın sonuçlarından yüksektir ancak sonuç ağır siklet bir boksörün yumruğunun ivmesini yansıtsa da modelin doğruluğu bilinmemektedir ve ayrıca bir boksörün değerleri tüm boks evrenine genellenemez. Diğer yandan Smith, Bishop ve Wells (1986) 3 tane amatör boksörün sol direk ve kroşelerinin ivmelerini ölçmüşlerdir. Onların bulguları ise bu çalışmadan düşüktür, fakat onlar sadece sol yumruklara odaklandıklarından bu çalışma ile kıyaslama yapmak doğru olmaz. Ama Walilko ve arkadaşları (2005) 7 tane olimpik düzey boksörün direk yumruklarını incelemişlerdir. Onların sonuçları doğal olarak bu çalışmanın sonuçlarından yüksek çıkmıştır.

Dikey Yer Tepki Kuvvetlerinin Tartışması

Bu çalışmanın sonuçlarına göre deneyim düzeyi ve yumruk tipi ile dikey yer tepki kuvvetleri arasında herhangi bir ilişki bulunamamıştır. Maalesef, daha önce boksta bununla ilgili yapılmış herhangi bir çalışma da bulunmamaktadır. Fakat, bu çalışmanın sonuçları tekvando da Park(1989)'ın yaptığı çalışmanın sonuçlarıyla tutarlılık göstermiştir. O da 3 farklı ön tekme vuruşu arasında herhangi bir dikey yer tepki kuvveti bulamamıştır. Mekanik olarak, boksta yeri kuvvetli bir şekilde itip öne adım atılarak yapılan vuruşlar yumruk atan ele daha fazla momentum aktarımına neden olur. Teorik olarak, yer yumrukta yeri kuvvetlice iterek güç kazanmak dikey yer tepki kuvvetlerinde bir fark yaratır. Fakat bu çalışmada fark çıkmamasının nedeni, boksörlerin sabit durarak yumruk atmalarından kaynaklanabilir.

Özetle, bu çalışmanın sonuçlarına göre, yerdeğiştirme, doğrusal hız, doğrusal ivme ve elin doğrusal ivmesi gibi kinematik değişkenlerin büyüküğünü belirleyen en önemli unsur atılan yumruğun tipi ve boksörlerin deneyim düzeyidir.

ÖNERİLER

Bu çalışmanın sonuçlarına göre ileride yapılacak çalışmalar için aşağıdaki önerilerde bulunulabilir.

1. Hız ve ivmenin ortaya çıkmasında ayakların, bacağın, kalçanın ve özellikle gövdenin hareketleri daha detaylı incelenmelidir.
2. İleride yapılıcak çalışmalarda ön ve arka ayağın yer tepki kuvvetleri ve vücudun ağırlık merkezinin yerdeğiştirmesi araştırılmalıdır.
3. Boksörler vuruştan hemen önceki el hızlarını artırmaya konsantre olmalıdırlar.
4. İleride yapılacak çalışmalarda yumruk kuvvetini arttırmak için elin hızını ve ivmesini geliştirmeye yönelik etkili antrenman yöntemleri araştırılabilir.
5. Boksörler yumruk kuvvetini artırmak için yağsız kas kütlelerini artırmayı düşünebilirler ancak bunu yaparken yumruk hızını da düşürmemek gerekir. Bu yüzden yağsız vücut kütlesini arttırırken çabukluk-çeviklikliği de geliştirmeyi ihmal etmemek gerekir.
6. Bir rakiple yapılan karşılaşma veya antrenman sırasında esnasındaki yumruk mekaniği de araştırılabilir.