Establishing the relationship between selected physical fitness parameters and the efficiency in Olympic clay target shooting

by

ZVONKO PELJHA

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ABSTRACT

This study aimed to optimise performance in the two Olympic clay shooting disciplines, Skeet and Trap, by providing empirical evidence on the critical fitness parameters that athletes and coaches should focus on during physical training. The first objective was to explore existing empirical research and gain a theoretical understanding and practical implications of selected fitness parameters in clay target shooting. In addition, relevant research results in other shooting disciplines were also examined. The second objective was to identify performance factors among the physical fitness parameters studied and determine their direct or indirect effects on shooting performance. In addition, the specific mental and psychomotor demands of Olympic clay target shooters and their relationships with other identified performance factors were examined. Based on the findings of the first two objectives, the next goal was to investigate the implementation of a training program specifically aimed at improving the identified performance parameters and whether further improvements in these parameters would lead to better shooting performance. The final objective was to determine the relative benefits of developing selected fitness parameters as a training strategy for novice and elite athletes in Olympic clay shooting.

The initial comprehensive review of the available scientific literature revealed that the current research in the field of Olympic clay target shooting lacks the necessary depth despite certain guidelines highlighting the importance of specific fitness parameters in other shooting disciplines. The findings of the desktop study were published in the *Journal of Human Sport and Exercise, 13*(3), and the paper titled 'The relative importance of selected physical fitness parameters in Olympic clay target shooting' was issued in 2018. Due to the lack of empirical evidence in this field, a subsequent study examined the relationship between selected fitness parameters and performance in clay shooting. The outcome of this investigation demonstrated that none of the tested parameters were statistically significant, suggesting that they cannot be regarded as important determinants of performance. In conclusion, an average level of the tested fitness components was adequate for achieving a high shooting performance, and further increases in these parameters would not improve shooting scores. However, an important finding from a later study was that elite shooters exhibited better bilateral symmetries in shoulder mobility and grip strength. This discovery encouraged further investigation into the potential effects of neuromuscular imbalances, and the results of this investigation were shared with the scientific community through a publication in the *Journal of Physical Education and Sport* in 2021, with the title 'Assessment of physical fitness

parameters in Olympic clay target shooters and their relationship with shooting performance'. To expand on the focus of previous research, modern computerised tests and traditional self-report assessments were used to examine psychological and psychomotor aspects that may contribute to Olympic clay shooting performance. The results of this investigation provide valuable insights into the coping strategies of Skeet and Trap shooters and their ability to overcome challenges, highlighting the significant role that coping skills play in this shooting sport. Subsequent research focused on further exploring the importance of bilateral neuromuscular symmetry, assessing the performance of competitive clay target shooters, applying individualised corrective training regimens to minimise detected asymmetries, and comparing results with shooting performance. The results of this investigation confirmed that neuromuscular asymmetries can negatively impact performance and that significant improvements in shooting performance were observed after minimising these imbalances.

In summary, this study provides novel information about performance factors that have not been studied previously and highlights the importance of symmetric rather than absolute values. The findings suggest that training programs to correct bilateral asymmetries should be incorporated into clay shooters' training regimes. The results of this study will subsequently help professionals involved in Olympic clay shooting better understand the importance of addressing and developing these aspects of the sport.

ACKNOWLEDGEMENTS

Pursuing a part-time PhD while working as a full-time physical education teacher and a physical fitness coach has been a truly remarkable and transformative experience. It gave me a unique opportunity to immerse myself in the academic domain of research and the practical world of sports education and coaching. The challenges I faced were substantial, but the rewards and personal growth I gained were equally extraordinary. As a physical education teacher and fitness coach, I had the privilege of working with a diverse range of pupils and athletes. From enthusiastic beginners and energetic three-year-olds exploring their physical capabilities to training elite national team members and participants preparing for high-level competitions like World Cups and Olympic Games, my responsibilities spanned the entire spectrum of physical and athletic development. This diverse teaching and coaching experience broadened my understanding of the various skill acquisition and physical development stages. It improved my ability to tailor my approach to suit the needs and aspirations of everyone under my guidance.

Undertaking a part-time PhD alongside my professional commitments demanded immense time management and organisational skills. I had to keep a delicate balance between fulfilling my academic responsibilities, meeting the demands of my teaching and coaching positions, and being present for my family as a dedicated husband and father. Additionally, being the only son, I was responsible for supporting and caring for my ageing parents, which added further complexity to the matter. In moments of exhaustion and self-doubt, the unconditional support of my loved ones and my desire for research and education inspired me to keep going. Pursuing a PhD in my area of interest enriched me with new knowledge and skills and enabled me to significantly contribute to the sport I have been professionally involved in since 2009. This study allowed me to explore new ideas, develop practical solutions and contribute to developing this shooting sports area.

Additionally, the insights I obtained through my doctoral studies impacted my career as I put the knowledge into practice to benefit my athletes. This integration of theory and practice not only elevated the standard of my coaching but also helped nurture the potential of young athletes and guide them towards successful sporting careers. On a personal level, the journey was equally transformative. The challenges and demands of managing a part-time PhD and a full-time career while also fulfilling my roles as a husband and father pushed me to grow as an individual. It taught me resilience, adaptability, and the importance of effective communication and collaboration with others. Despite the difficulties of this challenging project, my family always supported me and gave me the encouragement and understanding I needed. I am also profoundly grateful to my supervisors and mentors for their guidance and intellectual contributions along this path. Their expertise and constructive feedback helped shape my research and elevated its quality to meet the highest academic standards. Furthermore, the solidarity and encouragement from my colleagues and friends in the academic and sports communities played a significant role in keeping me motivated and inspired throughout the journey. Their shared passion for sports and education created an environment of continuous learning and growth.

In conclusion, the experience of pursuing a part-time PhD while working as a physical education teacher and a physical fitness coach has been a challenging yet immensely rewarding chapter in my life. It has given me knowledge and skills that have positively impacted my professional and personal life. The opportunity to contribute significantly to the sport I have actively pursued for many years demonstrates the importance of lifelong education and academic excellence. I have been fortunate to receive support, guidance, and motivation in my quest for academic advancement, and it is essential to express gratitude to the outstanding individuals and organisations that supported this academic undertaking.

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INTRODUCTION: The Context of the Research

Since 2009, I have worked as a physical fitness coach for Olympic Clay Target shooting. I have had the privilege of training athletes of various performance levels, including world champions, Olympic Games participants and National team members of Russia and Cyprus. Since my involvement in the Clay Target shooting started, I have noticed a lack of scientific studies and research papers focusing on the physical requirements for athletes competing in this sport. My initial approach was based on insights shared by coaches, doctors, physiotherapists and athletes within the shooting community. This anecdotal approach motivated me to investigate how specific fitness components can impact performance in Olympic clay shooting. It was inspiring to consider conducting a study and bringing a scientific perspective to this field, given my extensive experience as a specialised fitness coach. Based on my practical knowledge of working with athletes of various levels, I recognised this was a unique opportunity to conduct empirical research and take a more scientific approach to this area of the clay shooting sport.

This thesis searches into the complex relationship between specific fitness parameters and the efficiency of Olympic clay target shooting. This exciting and highly competitive sport demands peak mental and physical capabilities from its participants. Based on existing scientific research from different shooting disciplines, it is evident that competitive shooters need excellent technique and specific psychological and physical skills to perform at the highest level. Undeniably, technical training is the keystone of a competitive shooter's routine. Still, some authors (Mon, 2015) suggest that physical condition plays a critical role in achieving high-performance levels in shooting and that the significance of physical training should not be overlooked. If we consider two shooters possessing equivalent techniques, the one in better shape has the upper hand because he will have better endurance, improved posture, more excellent stability, and better health, which results in a more positive attitude. It was brought forward by Suppiah et al. (2019) that to enhance their shooting performance, shooters must develop their muscular strength. For example, pistol shooting performance is impacted by the strength of the forearm and deltoid muscles (Mon, 2015). Also, the investigation of Svecova et al. (2016) has shown that strengthening these muscles through hand grip exercises is crucial for pistol shooters, as the increased tension in these muscles can have a direct effect on the trajectory of the gun, making hand grip strength training programs an essential part of pistol shooting preparation. Balance is another crucial physical fitness component explored in various shooting disciplines (Su et al., 2000; Bayati et al., 2016; Koley & Uppal, 2016). A stable shooting position requires shooters to adopt a stable and repeatable shooting position to ensure consistency, and it involves precise body alignment, foot placement, and balance (Köykkä & Häkkinen, 2017). In addition, the shooter needs to stabilise their firearm and control the movement of their body's kinetic lines. The correlation between the gun's motion and the shooter's movements, particularly with their upper body strength and overall stability, suggests that athletes who possess greater balance may minimise unwanted movements and body sway to a minimum. Competitive shooters and their coaches have long understood that body sway impacts performance, and research has consistently demonstrated a clear correlation between a decrease in body sway and superior performance in disciplines such as air pistol and running target (Mon et al., 2019). In addition, Hue et al. (2007) showed that heavier shooters exhibited significantly less body sway compared to lighter shooters. Regarding the cardiovascular system, it was reported by Svecova et al. (2016) that a more robust heart recovers more quickly and stays closer to its average rate when the shooter is under psychological and physical pressure. Also, Mon et al. (2016) report that the average heart rate of experienced competitive shooters during the pre-performance phase is notably lower than that of novice or untrained shooters. Further, while trigger control and sight picture are crucial for all shooters (Lawson et al., 2016), higher-performing shooters prioritise gun stability over visual-motor aspects, as opposed to less experienced shooters who emphasise the latter (Tommasi et al., 2015). In addition, Tommasi et al. (2015) suggests that improving visual-motor skills and stimulating cognitive resources can significantly enhance performance by reducing tremors. Physiological tremors, which are generally invisible, might worsen due to physical exhaustion and intense emotions. Supplementary, using scientific instruments, electronic systems, and other devices, gun handling patterns and control can be detected and analysed to determine their impact on shooters of varying skill levels. The data from these studies suggest that experienced shooters display smoother and more efficient movements when aiming their firearms, unlike novice shooters (Mon, 2019).

In the constantly developing world of competitive sports, the pursuit of excellence is often determined by countless factors, and the sport of Olympic clay target shooting is no exception. As clay shooting athletes strive for perfection, the focus has traditionally been on shooting skills, mental preparation, and optimising equipment. However, recent advancements in sports science have revealed the potential influence of physical fitness on shooting efficiency (Mon, 2015). Throughout the history of Olympic clay target shooting, it changed from a pastime to a popular sports spectacle, where precision, focus, and coordination join into an art form. Consequently, the significance of physical fitness as a crucial factor for peak performance has become ever more evident, assuring the need for an in-depth exploration of this domain. In this ambitious attempt, I commenced a revealing and comprehensive exploration of selected physical fitness parameters and their potential correlation with shooting efficiency in the Olympic clay target disciplines. Through an extensive examination of key elements, including cardiovascular endurance, muscular strength, flexibility, reaction time and hand-eye coordination, I aimed to clarify the needs in specific physical conditioning for better shooting accuracy, consistency, and overall performance. Indeed, the knowledge obtained from this extensive and pioneering research will serve as a clarification for athletes, coaches, and scientists involved in these sports. Equipped with these invaluable insights, training programs and preparation strategies can be more accurately tailored to harness athletes' full potential, assisting in a time of unparalleled competitiveness and excellence in shooting sports. It was an exciting and captivating journey as I explored the importance of physical fitness for the art of competitive clay target shooting and how it can contribute to peak performance and push the limits in this extraordinary and widely embraced Olympic discipline.

CHAPTER 1: **The Art of Precision: An Introduction to Olympic Clay Shooting**

1.1 THE BACKGROUND OF OLYMPIC CLAY SHOOTING

In general, shooting sports can be categorised into two main groups. The first group consists of precision target disciplines where shooters aim at stationary targets (e.g., archery, pistol, rifle shooting). The second group includes all the shotgun shooting disciplines, which require hitting targets that move quickly within a defined area. Competitive shotgun shooting originates from bird hunting simulation and has developed into a sport with more than 20 regulated disciplines. Two disciplines, Trap and Skeet, are part of the Summer Olympic Games program. Competitive shotgun shooting uses specialised flying targets known as clay pigeons or clay targets. In Trap and Skeet events, the disc-shaped targets measure 11 cm in diameter and 2.5 cm in height. During the semi-finals and medal matches, 'flash' targets containing green or orange powder are used, creating a puff when hit for a better visual effect. In this type of shooting, the gun fires a projectile containing 300–450 small spheres, called a shot or pellet. For the Olympic disciplines, a 12-gauge, single-trigger, over-under shotgun, loaded with a maximum of 24.5 grams of smooth bored shell pellets, is commonly used (Wilson, 2013). Additionally, a particular target-throwing device, a *trap*, is essential for competitive clay shooting. These machines are typically positioned in a trap-house bunker to provide safety from stray shots and weather conditions. In Trap events, the bunker is placed 15 meters in front of the shooter, while in Skeet, the machines are positioned in two houses at different heights, one at each end of the range (Figures 1 & 2).

The International Shooting Sport Federation (ISSF) governs all Olympic shooting events and was established in 1907 as the International Shooting Union. The organisation changed its name to ISSF in 1998, with its headquarters located in Munich, Germany, and currently, the ISSF supervises over 150 National Shooting Federations. According to ISSF regulations, Trap and Skeet have been part of the Olympic Games since 1900 and 1968. Presently, the Olympic clay shooting disciplines include five events: Trap for Women, Trap for Men, Skeet for Women, Skeet for Men and Trap mixed team, consisting of one female and one male competitor. The double trap event was once included in the Olympic program but was removed for women after the 2004 Summer Olympics and for men before the 2020 Olympics. The ISSF also modified the shotgun shooting rules after the 2012 Olympic Games. The most significant change was that qualification and semi-final scores were no longer carried over into the final round, so all participants started with a zero score in the final stage of the competition. After the semi-finals, the two highest scorers advance to the gold medal match, while the third and fourth-ranked shooters compete for the bronze medal.

1.2 OLYMPIC SKEET

In both Skeet events, male and female athletes participate in shooting activities across eight stations. These stations contain bunkers situated in two separate 'houses' positioned 40 meters apart. The 'high house' is on the left side (H in Figure 1), while the 'low house' is on the range's right (L in Figure 1). The saucer-shaped clay targets are launched from the 'high house' at a height of 3.05 meters and from the 'low house' at 0.9 meters above the ground. These targets follow a consistent trajectory, diagonally and away from the shooter (as shown in Figure 1). Both targets can achieve a speed of up to 78 km/h at the centre of the field and reach a maximum height of 4.6 meters. In the qualification round, shooters are organised into squads of five or six athletes, and they take turns shooting from stations 1 to 8, initially rotating from left to right. The shooting round begins at Station 1, near the 'high house', where the competitor loads the gun with one cartridge and then calls for the target, launched within a varying time of 0.2–3 seconds from the nearby 'high house'. Then, the athlete loads two cartridges, prepares, calls for the target, and shoots simultaneously at two discs thrown from both 'trap houses'. This procedure is repeated at Stations 2 and 3, followed by two single shots at Station 4, a single and double shot at Stations 5 and 6, and one double shot at Station 7. Afterwards, two doubles are shot again at Station 4, and finally, two singles are shot from Station 8, completing 25 shots. During the competition, athletes take turns shooting at each station, moving to the next one as soon as all shooters in the squad have fired their shots from the current station. Each competitor must shoot 125 targets during an official competition, divided into five rounds of 25 targets over two or three days. The six highest-ranking shooters proceed to the final round with a zero score and start from station number 3 with two doubles, followed by one double at station number 4 and two more doubles at station number 5. After finishing another round similarly, the athlete with the lowest score is eliminated and takes the sixth position. This process continues with one more athlete being eliminated at the end of each subsequent round. Finally, the same procedure is used to determine the gold and silver medals in the last round. In case of a tie, shoot-offs will be carried out by assigning the shooters to stations 3, 4 or 5 according to the number of participants and the shooting order. The shooters first shot a single target from a higher house, then a lower house, and then shot two targets simultaneously from both houses. The shooter with the lowest score is eliminated, and the remaining shooters continue shooting until only one shooter remains.

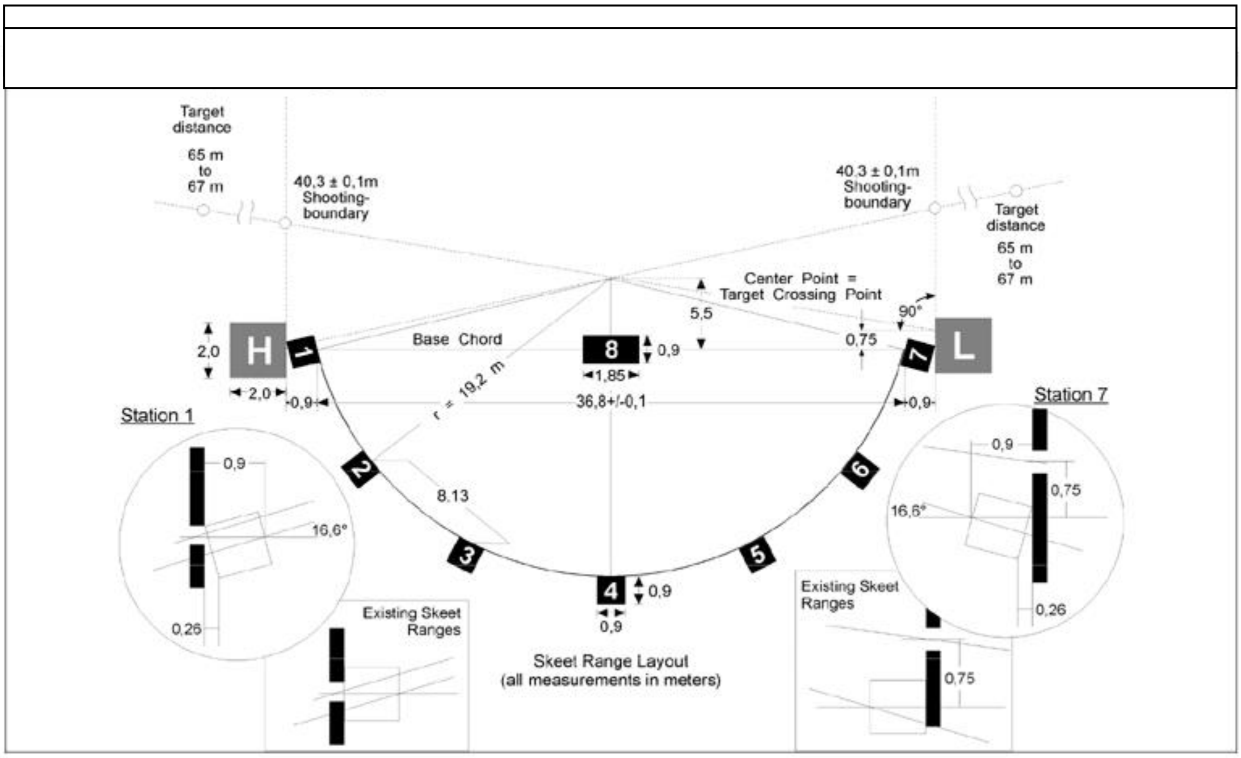


Figure 1: Skeet shooting range

1.3 OLYMPIC TRAP

At the Olympic Trap event, participants shoot at single clay targets in both the male and the female categories. The clay targets are discharged from five different stations, called ‘trap bunkers’, located 15 meters before the athletes' standing position (see Figure 2). Each target is launched at a high speed of 110 km/h at an unknown angle. In qualifying rounds, if the first shot misses the target, the shooter is allowed to shoot a second time at each of the 25 targets. Alike in Skeet, the trap shooters must complete five rounds of 25 targets, spread over two or three days, adding up to 125 targets, with the possibility of additional targets at the shoot-offs. After shooting at the target from their assigned starting position, the athletes move to the next station on their right, allowing the following shooter to take their turn. The shooters are grouped into five or six-member squads depending on the organisation and the number of participants at a competition during the qualification rounds. The athletes take turns shooting at one target from each station numbered 1 to 5, rotating from left to right until they have fired five shots from each station. In the case of a squad with six athletes, the sixth athlete waits for his/her turn, initially positioned behind station number 1. After the athlete at station number 5 completes the shot, the potential sixth athlete moves into station 1, and the shooter from station 5 waits behind him at the first station. The six highest-scoring athletes from the qualification phase proceed to compete in the final. Shoot-offs are carried out in the case of an even score during the qualification round. During the shoot-offs, the athletes take turns shooting at a single target until one of them misses, determining their position. Regardless of the results of the qualifications, in the final, the six best shooters start with a zero score; however, they are allowed only one shot per target. In the final round, the six finalists follow the same rotational pattern as in the qualification rounds, shooting from each station five times a single shot. After the fifth round, the athlete with the lowest score is eliminated, finishing in sixth position. The process repeats with another round of five shots, excluding another athlete in fifth place. Equally, the fourth and third positions are determined. The two remaining athletes engage in two more shooting rounds to decide the gold and silver medallists. A potential tie is resolved once again with a shoot-off.

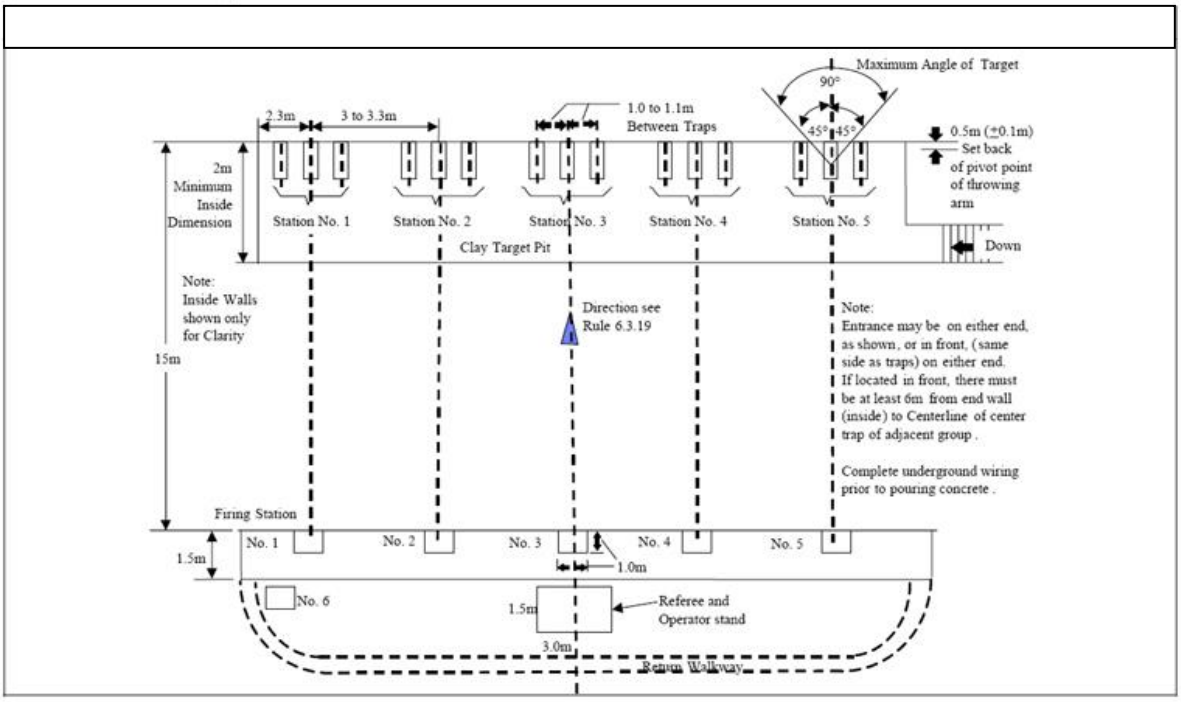


Figure 2: Trap Shooting Range

1.4 OLYMPIC TRAP - MIXED TEAM

Another event at the Summer Olympics is the Mixed Trap Team discipline, which consists of teams of one female and one male shooter. The qualification rounds for this event follow the same procedure as in the individual Trap events, but in this case, six shooters form three teams of two. All competitors shoot three rounds of 25 targets, allowing for a maximum of 75 targets to hit per athlete and 150 targets per team. Identically to the individual events, two shots are permitted at each target during the qualification rounds, while only one shot is allowed in the finals. The six highest-scoring teams from the qualifiers advance to the finals, where teammates take turns shooting five rounds of five targets each for a maximum score of 50 points. After each shooter takes five shots at each station, the team with the lowest score will be eliminated and ranked sixth. Subsequently, the fifth, fourth, and third-place rankings are determined at the end of each following round. The remaining two teams then complete two additional rounds to decide the gold and silver medallists. Shoot-offs are carried out in case of ties, as in the individual Trap event.

1.5 SPECIFICITY OF OLYMPIC CLAY TARGET SHOOTING

Shotgun shooting involves shooting at targets travelling at high speed, displaying the fundamental difference in movement patterns between the stationary and the clay shooting disciplines. Despite the apparent difference between the two shooting categories, it is still uncertain if the requirements in physical fitness are similar. In archery, rifle, and pistol shooting disciplines, the athletes shoot at a stationary target, where successful performance depends on the exact knowledge of the target positioning (Roberts & Turnbull, 2010), differently in clay target shooting, where the target is slightly larger and moves rapidly in a predefined space. Also, from the ballistics perspective, the shotgun shows noticeable differences from the single projectile used with the bow, pistol, or rifle. Specifically, the latter two have bullets with perfect ballistic shapes, high velocity, and sectional density. On the contrary, in shotgun shooting, the goal is to hit a fast-moving target by producing a more efficient target area saturation so that many of the ideal ballistic properties of pistol and rifle shooting are sacrificed (Wilson, 1978). Compared to stationary disciplines, the clay shooter must wait for the target to appear in his field of vision, mount and follow the clay disc that moves at a speed of 20-30 m/sec before pulling the trigger. When following and shooting at the target, the clay shooter must energetically move the upper body and simultaneously handle a 12-gauge shotgun with unsupported arms. Considering the gun's weight (approx. 4kg) and the fact that an elite athlete shoots between 100-300 targets during a training session, immense stress on the musculoskeletal system of the clay target shooter is generated. Moreover, with every fired shot, the shooter endures a recoil with a horizontal force peak of up to 180kg (Hall, 2008), putting the athlete's body under enormous strain. The clay shooter is also positioned differently than competitors in other shooting disciplines. The athlete must take a comfortable and stable *ready position* to maintain balance during the dynamic movement and to minimise physical strain so that he/she can save energy for the needed cognitive functions, specifically for prolonged concentration, mental alertness, and adequate fine motor skill (Rossi & Zani, 1991). The main difference in body positioning between the two Olympic clay shooting disciplines is that the shotgun is on the dominant shoulder, ready to fire in Trap shooting. At the same time, in the Skeet discipline, the gun is locked under the dominant arm with the stock visible below the elbow line and touching the marker line on the shooting vest (see Figures 3 & 4).

Figure 3: Trap Shooter in Ready Position

Figure 4: Skeet Shooter in Ready Position

The first protruding fitness component required in both disciplines is postural stability. Rajach and Rakumar (2018) define stability as the capability to respond to a perturbation. Gasperini (2020) pointed out that staying stable during movement by resisting external forces is essential for a successful performance in both disciplines. Since the first scientific indication of the importance of steadiness for marksmanship by Spaeth and Dunham (1921), many other authors confirmed the positive correlation between stability and success in shooting from a variety of weapons (Bayati et al., 2016; Koley & Uppal, 2016; Stambolieva et al., 2015; Konttinen et al., 2014; Sattlecker et al., 2014; Kayihan et al., 2013; Koley & Gupta, 2012). Although only one published study existed in this domain for Olympic clay shooting by Puglisi et al. (2014), confirming the positive relationship between good balance and performance in the Skeet discipline, improvement of this fitness component is highly recommended in the National Coach Manual with the title *Clay Target Ready Position* issued by the International Shooting Sport Federation (Gasperini, 2020). However, the works of other authors provide inconsistent evidence on the matter and deny such a positive correlation of stability to shooting performance (Ihalainen et al., 2015; Zemkova, 2013; Anderson & Plecas, 2000; Era et al., 1996; Stuart & Atha, 1990).

Consequently, there is a need to clarify this contrast in future investigations. Further, the official ISSF Coach Course Handbook recommends developing the Olympic clay shooters' physical abilities by focusing on strength, endurance, reaction time and specific coordination (Gasperini, 2020). However, no empirical evidence is available for these recommendations, nor is there a methodology for improving those fitness components or to what extent those parameters would positively impact performance. Only one study regarding shooting sports and endurance levels by Mondal et al. (2011) is available, and it focuses on the VO2 max levels of rifle shooters. The authors concluded that the endurance levels of the examined athletes were average, close to that of other anaerobic sports, like discus throwers and weightlifters. Empirical evidence has not been available in reaction time demands or sport-specific coordination for Olympic clay shooters. Similarly, only a few studies from other disciplines are available for specific demands in strength (Mon et al., 2015; Kayihan et al., 2013; Koley & Gupta, 2012) based on an evident involvement of the muscles of the midsection, shoulder girdle, arms, and forearms. To what extent do the recommended fitness components by the ISSF play a role in a more successful performance in Olympic clay shooting? This is yet to be investigated.

1.6 ASPECTS OF PERFORMANCE FOR OLYMPIC CLAY SHOOTING

Optimum performance in any sport is a complex achievement that relies on the coordinated association of technical, physical and psychological aspects. Each of these dimensions plays a critical role in an athlete's ability to excel in their sport, and elite clay target shooting is no exception. The Skeet and Trap disciplines have evolved into one of the most captivating shooting disciplines at the Summer Olympic Games, requiring high precision, focus, and adaptability. Competitors in both disciplines are engaged in a contest of skill in an attempt to hit fast-moving clay discs with a split-second accuracy. To excel in these disciplines, athletes must satisfy various demands, such as technical mastery, specific physical conditioning, psychological resilience, and adapting to changing environmental conditions. Besides the apparent physical demands, which are the study's focus, it is vital to highlight the importance of the remaining aspects for high-level performance in this sport. Although precise quantitative distributions for performance factors in Olympic clay target shooting are not yet established in the literature, insights from related shooting disciplines offer a logical basis for estimation. Based on research in similar precision sports (Mon-López et al., 2022; Mon-López et al., 2019; Vickers, 2007), it is reasonable to conclude that technical skill contributes approximately 45-55% to performance, psychological factors account for about 35-45%, and physical conditioning for 15-20%. These proportions are derived from general trends observed across shooting sports, where technical precision and psychological resilience are critical, as supported by foundational research in the field (see Figure 5). These estimates depend on circumstances and can vary from athlete to athlete. Nevertheless, the psychological demands of clay shooting—such as concentration, anxiety management, and emotional regulation—are indeed more pronounced than in many other sports (Abernethy & Neal, 1999; Behncke, 2004; Raglin & Hanin, 2000; Vickers & Williams, 2007).

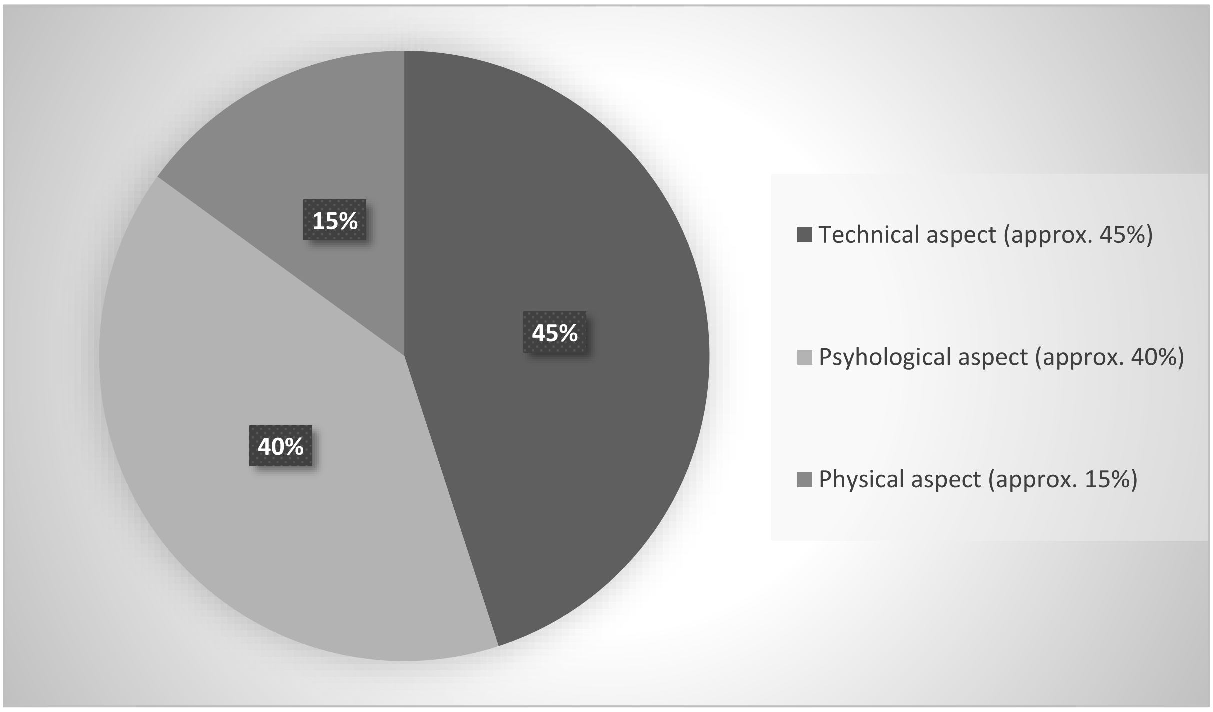


Figure 5: Estimated contribution of performance factors in Olympic clay target shooting based on analogous findings in precision shooting sports.

1.6.1 Precision in Motion: The Technical Mastery of Clay Shooting

The first technical aspect of every sports discipline is the development of specific skills for technical competence. Athletes must master the techniques and skills required in their sport by following a purposeful and structured practice (Ericsson et al., 1993). Further, it is imperative to have a detailed understanding of the discipline's rules, regulations, tactics, and strategies. Good comprehension positively affects the athletes' perceptual and decision-making skills and is essential for successful performance (Helsen & Starkes, 1999). In addition, Köykkä and Häkkinen (2017) emphasised the importance of maintaining consistency in technique for athletes involved in shooting sports. Further, the authors pointed out the need for shooting athletes to replicate their form with precision shot after shot. Moreover, mastering the equipment is another essential aspect of successful shooting, as pointed out by Burris and Hodgdon (2000). Further, the authors concluded that shooting athletes must confidently understand their firearms, munitions, optics, and accessories while executing consistent shooting accuracy. Another important aspect of consistent athletic performance is injury prevention. Therefore, biomechanical aspects and injury prevention strategies should be part of every athlete (Bahr & Krosshaug, 2005).

1.6.2 The Mind's Eye: Psychological Strategies in Clay Target Shooting

The psychological aspect of clay target shooters plays a vital role in achieving optimal performance, as this psychophysical activity involves a complex interaction of psychological, technical and physical factors. The ability to perform well under pressure and adapt to changing conditions depends largely on the athlete's mental resilience and strategic thinking. Mental toughness is considered to be one of the basic elements of excellence in any sport that enables a competitor to maintain the most efficient execution in performances under pressure. Jones et al. (2002) define mental toughness as a multi-dimensional construct including self-belief, motivation, focus, and emotional control attributes that help athletes overcome adversity, sustain high performances, and cope psychologically with competition demands. Mental toughness is essential in skeet shooting, as athletes must hit many targets with minimal errors. Maintaining focus and composure over multiple days of competition is essential for success. Maintaining focus and concentration is essential in precision sports such as shooting, as athletes must effectively eliminate all distractions and focus entirely on the target. According to Haberl and Haberl (2012), attention control plays an important role in improving performance, and shooters often use strategies such as focusing on breathing and visualization to maintain focus. Vickers and Williams (2007) highlighted the importance of mental training for achieving high performance in clay shooting disciplines. They concluded that experienced shooters showed better visual focus and concentration compared to novices. Consistency is also a key factor in clay shooting, and emotional regulation plays a vital role in maintaining a consistent performance. It is essential to remain emotionally neutral and avoid overreacting to successful and unsuccessful shots. Behncke (2004) reports that emotional regulation strategies, such as mindfulness and relaxation techniques, are essential for achieving consistent performance in precision sports. In addition, goal setting is an important strategy to increase motivation and guide individuals to success. According to

Locke and Latham (2002), setting clear and challenging goals can significantly improve an athlete's performance by providing them with a sense of purpose and direction. This is crucial in clay shooting because setting goals allows athletes to focus on incremental improvement and maintain long-term motivation.

Further, visualization and mental imagery are powerful tools for athletes to prepare for competition mentally. A study by Smith et al. (2007) on the effectiveness of imagery in shooting sports found that shooters who regularly used mental imagery performed significantly better than those who did not. Similarly, Driskell et al. (1994) found that mental training can improve performance by improving skills, reducing anxiety, and increasing self-confidence. Visualizing successful shots and mentally practicing the sequence of movements in shooting sports can help shooters execute their techniques more consistently. Similarly, clay shooters must be highly adaptable and able to handle different environmental conditions, such as wind, rain, and extreme temperatures. Vickers (2007) highlights the importance of adaptability for athletic performance and suggested that athletes must be able to adjust their techniques and strategies to changing conditions. Mental adaptability allows clay shooters to remain calm and focused even when faced with unexpected challenges. In addition, coping with competition stress is another important psychological aspect of shooting sports. Hays (2016) believes mental adaptability is essential to cope with different conditions and competitive stressors. Effective stress management techniques such as relaxation exercises, cognitive restructuring, and mindfulness can help athletes stay calm and perform at their best.

In summary, the mental aspects of clay shooting performance play a vital role in enabling athletes to achieve their best performance. Mental strength, focus, goal setting, visualization, adaptability, and stress management are all key elements that help athletes excel in this demanding sport. Understanding the complexities of the sport and developing these mental skills is vital not only for athletes, but also for coaches, sports psychologists, and other professionals involved in their training and development. A holistic approach ensures that athletes are fully prepared for the mental and physical challenges of competition and perform to their highest potential.

1.6.3 The Interplay of Physical and Psychological Aspects in Neuromotor Skills

As Williams and Ford (2008) pointed out, neuromotor skills can be viewed as a combination of the mental and physical aspects associated with sports performance. Neuromotor skills involve coordinating the nervous system and muscles to execute precise movements and actions, which are essential for high-precision sports such as clay shooting. These skills include a range of functions such as balance, coordination, agility and fine motor skills, all of which are essential for achieving optimal performance.

The physical aspects involve the development and improvement of muscle control and coordination. These include strength, flexibility, and the ability to execute movements precisely and efficiently. Additionally, excellent hand-eye coordination is essential for sports such as clay shooting. This physical ability relies on the combination of visual input and motor responses. Equally important is the psychological aspect of neuromotor skills, which is critical and complex. Cognitive processing plays a significant role, as these skills rely on the brain's ability to quickly and accurately process information, including decision-making, reaction time, anticipation and response to stimuli. Maintaining high focus and concentration levels is essential for executing fine motor skills, particularly in precision sports. Additionally, psychological factors include motor learning and memory processes, which enable athletes to develop and refine their motor skills through practice and experience.

In conclusion, clay target shooting performance relies on the combination of various aspects, such as the coordination of the nervous system and muscles, and is controlled by cognitive processes and mental concentration. Understanding and training in all facets can greatly improve the shooter's ability to perform complex movements accurately and consistently.

1.7 AIM AND OBJECTIVES

The main aim of my thesis is to provide recommendations for a sport-specific physical training program that will have the greatest positive impact on shooting performance in the Olympic Skeet and Trap shooting disciplines. The primary objective of my research is to identify the key fitness elements that have the greatest impact on clay shooting performance. The central question focuses on identifying the fitness parameters that have the greatest direct or indirect impact on shooting accuracy in Skeet and Trap. As with any competitive sport, particularly an Olympic sport, where the smallest detail can determine whether the athlete qualifies for a final or finishes as first or second in a competition, it is crucial to scientifically determine what fitness parameters support the most successful performance. While most elite clay shooters engage in some form of physical training, their methods are based on personal experience, making their work more anecdotal than scientific. The presented study aimed to clarify the exact needs of Olympic clay shooters in this domain and provide preliminary empirical evidence on how competitive clay shooting athletes should be physically conditioned by identifying key fitness parameters that athletes and coaches should focus on for performance optimisation. The most important question to be answered was which fitness parameters are most relevant to shooting accuracy in the Skeet and Trap disciplines. Therefore, this thesis aimed to provide evidence-based data to improve coaching practice by identifying the importance of specific physical parameters for improving performance. To attain this purpose, the study investigates the following research questions:

1. How can existing empirical research contribute to a comprehensive understanding of the theoretical explanations and practical significance of selected physical fitness parameters in clay target shooting?
2. What insights can be gained by examining relevant research from other shooting disciplines, and how might this information be applied to enhance understanding within the context of clay target shooting?
3. What are the performance factors among the studied physical fitness parameters, and how do they influence shooting performance directly or indirectly?
4. What are the specific mental and psychomotor demands experienced by Olympic clay target shooters, and how are these demands associated with other identified performance factors?
5. How effective is implementing a specially designed training program in enhancing the identified performance parameters, and to what extent does improvement in these parameters correlate with enhanced shooting performance?
6. What are the relative benefits of developing the selected physical fitness parameters as a training strategy for novice and elite Olympic clay target shooting athletes?

1.8 CENTRAL QUESTION AND CONTRIBUTION

The central question addressed in the study was the identification of physical fitness parameters that show the strongest positive correlation with performance in Olympic clay target shooting. These parameters will potentially contribute to performance optimisation by establishing the physical fitness parameters that impact shooting efficiency most. This will help athletes and coaches involved in the sport to focus physical conditioning on the most relevant aspects to maximise shooting performance.

Further, identifying key fitness parameters can help develop an injury prevention program to minimise the negative impact of repetitive movements and recoil on the musculoskeletal system, particularly the shoulders, neck, and upper back. Reducing overuse injuries increases the clay shooters' chances of performing more efficiently and extending longevity in the sport.

Additionally, coaches and scouts can more effectively identify promising athletes by identifying key physical fitness parameters. Talent development programs and evidence-based support for skill development in young athletes can be introduced to increase their chances of reaching elite levels. Likewise, training optimisation based on scientific knowledge can provide personalised training recommendations for each athlete, resulting in more effective training and, ultimately, better performance.

Also, better mental and physical health, developed by improving specific fitness components that are proven to positively affect clay shooting athletes, resulting in increased confidence and focus. The knowledge of the direct or indirect positive impact of specific fitness components on shooting accuracy can motivate athletes to prioritise their overall health, leading to better preparation, reduced stress levels, and improved mental resilience during competitions.

Furthermore, competitive advantage can be achieved, especially with world-class performance, because even minor improvements to key components can significantly affect results. Athletes and coaches who know how to improve key physical parameters can gain a competitive advantage over their opponents and increase their chances of success. This will potentially encourage further scientific research in this area to develop sport-specific training programs that can help improve shooting performance.

In summary, determining the relationship between specific physical fitness parameters and efficiency in Olympic clay target shooting can transform how athletes train and compete. By applying this knowledge, coaches and athletes can optimise the training processes, reduce sport-specific injuries, enhance performance, and elevate the standards of clay target shooting overall.

1.9 METHODS

Quantitative research methods and performance analysis were applied to identify the physical fitness parameters with the strongest positive correlation with shooting performance in Olympic clay target shooting. To examine the first objective, an extensive literature review was undertaken to explore the existing empirical knowledge about fitness parameters in shooting sports, mainly focusing on studies related to the Olympic clay target disciplines. Additionally, a cross-disciplinary comparison with physical demands in other shooting sports, such as rifle and pistol shooting, was performed to identify any overlapping fitness demands in objective 2. The results obtained from investigating objectives 1 and 2 formed a knowledge base and identified gaps that needed to be addressed.

The following study focused on objective 3, examining a sample of competitive Skeet and Trap shooters on a wide range of physical fitness parameters, including strength, endurance, flexibility and reaction time. Simultaneously, the most recent shooting results from formal competitions were gathered. The correlation between selected physical fitness parameters and shooting scores was then analysed using the SPSS statistical analysis software, identifying which parameters show the strongest positive correlation with higher shooting results. Additionally, a multiple regression analysis was performed to determine whether a combination of fitness parameters might be more predictive of better shooting performance than individual parameters alone to identify potential interactions between different fitness factors. Further, skill level differentiation was examined, and whether specific fitness parameters can distinguish skill levels within Olympic clay target shooting by comparing the anthropometrics and fitness test results of novice, intermediate and elite shooters. The fourth objective was to examine Olympic clay shooters' specific psychological and psychomotor demands and their associations with other identified performance factors. For exploring objective 5, a longitudinal intervention study was conducted over an extended period to track changes in the discovered fitness parameters and shooting performance to identify whether improvements in the selected fitness parameters lead to enhanced performance. The findings of the primary studies were summarised in comprehensive research papers and published in a relevant academic journal to share the findings with the scientific community, coaches, and athletes to improve training methods and performance in Olympic clay target shooting (Peljha et al., 2021; Peljha et al., 2018).

CHAPTER 2: The relative importance of selected physical fitness parameters in Olympic clay target shooting

2.1 INTRODUCTION

Clay target shooting involves shooting from a particular shotgun at flying targets, known as clay pigeons or discs. The gun uses 7 cm long cartridge ammunition, with 12-gauge shells containing 24 grams of equally weighing spherical balls made from lead, called pellets, or shot. Although clay target shooting has more than twenty individual disciplines, most can be arranged into three basic categories: Sporting, Skeet and Trap, with the latter two being part of the Summer Olympic program (see Chapter 1). The first and second objectives of my research were to conduct a detailed systematic review of the existing empirical evidence on the role of specific fitness parameters in the disciplines of Skeet and Trap and related shooting sports, considering the apparent differences between precision targets and the shotgun shooting disciplines. The pistol and rifle shooting disciplines consist of aiming at a stationary target, where exact knowledge of the target is essential to an effective execution (Roberts & Turnbull, 2010). However, in shotgun shooting, the target is bigger but moves at a high speed inside a predefined space (see Chapter 1). The clay shooter mounts, aims, follows the target and executes the shot after dynamically moving the body in a unique way for shooting sports. Such energetic repetitive movements constantly strain the musculoskeletal system, in addition to handling the 4kg heavy shotgun with unsupported arms. The differences in physical demands and movement patterns should be explained to understand better the unique needs for sports-specific fitness in the different shooting disciplines. To this end, a systematic literature review was conducted to assess the essential fitness elements required for various shooting sports. According to Liberati et al. (2009), a systematic review attempts to answer a specific research question by obtaining available empirical data that matches the pre-specified criteria. Therefore, the following questions for Objectives 1 and 2 were addressed: (1) What is the present-day state of published scientific work on the importance of selected physical fitness parameters in Olympic clay shooting? (2) What data are available in the same field in other shooting sports? (3) Which scientific research from other shooting sports could have a relevant transfer to the Olympic clay shooting disciplines?

2.2 METHODS

A comprehensive review of current scientific literature was performed to summarise the significance of selected fitness parameters in clay target shooting and related disciplines. The search for relevant scientific articles involved using specific keywords such as 'skeet,' 'trap,' 'eye-hand coordination,' 'strength,' 'pistol,' 'rifle,' 'clay target shooting,' 'postural balance,' and 'shooting sports.' To gather a wide range of information, I extensively searched through four primary online databases: EBSCOhost, PubMed, Emerald Insight, and Google Scholar. The examination of complete articles, abstracts, and titles from the initial search revealed key terms, leading to the inclusion of additional search items. Only reports published in English that focused on the physical fitness parameters of participants competing in clay target shooting or other shooting disciplines were included. The final search was completed on September 1, 2017, covering all scientific papers published up to that date. My two supervisors played a key role in assessing the search results for eligibility based on the inclusion criteria. They carefully reviewed each result, using their expertise to ensure we included only relevant, high-quality studies. By independently checking and discussing uncertain cases, they ensured our selection process was detailed and consistent, greatly improving the reliability of the research. Out of the initial 51 publications identified for review, only three were directly related to the Olympic clay shooting disciplines at that time. Without sufficient evidence, scientific journals from other shooting disciplines were also reviewed. Consequently, the Results section includes all shooting disciplines, organized under four main categories that emerged. This approach aimed to bridge the gap in the literature and draw applicable insights from a broader range of shooting disciplines to enrich our understanding of Olympic clay shooting.

2.3 RESULTS

Objectives 1 and 2 focused on conducting a systematic review to assess the significance of specific physical fitness parameters for shooting sports, focusing primarily on the Olympic Skeet and Trap events. Throughout the comprehensive literature review, it became evident that many studies did not align with the research objectives. Some of these studies explored unrelated topics, such as the ecological impact and environmental effects of lead pollution near clay target shooting ranges (Baer et al., 1995; McTee et al., 2016; Migliorini et al., 2004; Rooney & McLaren, 2000; Sorvari et al., 2006; Vyas et al., 2000). The only relevant discovered study was the research by Puglisi et al. (2014), exploring the correlation between postural stability and performance of Skeet shooters (see Figure 6). According to the findings of this study, elite performers demonstrated significantly better postural control compared to less skilled shooters. In summary, the authors concluded that improved postural control is positively associated with shooting performance, and they recommended improving motor control and incorporating anaerobic and balance drills into the training routines of Skeet shooting athletes. Other two related studies, conducted by Swanton (2011) on gun movement kinematics during Trap shooting and Causer et al. (2010) on gun barrel kinematics and the 'quiet eye' duration, were not in direct relevance to the research interests of this investigation. Overall, one of the most apparent findings from my desktop study is the lack of scientific research regarding fitness parameters that can improve performance in Olympic clay shooting and the scarcity of studies aligned with the research objectives underscored the need for further scientific research.

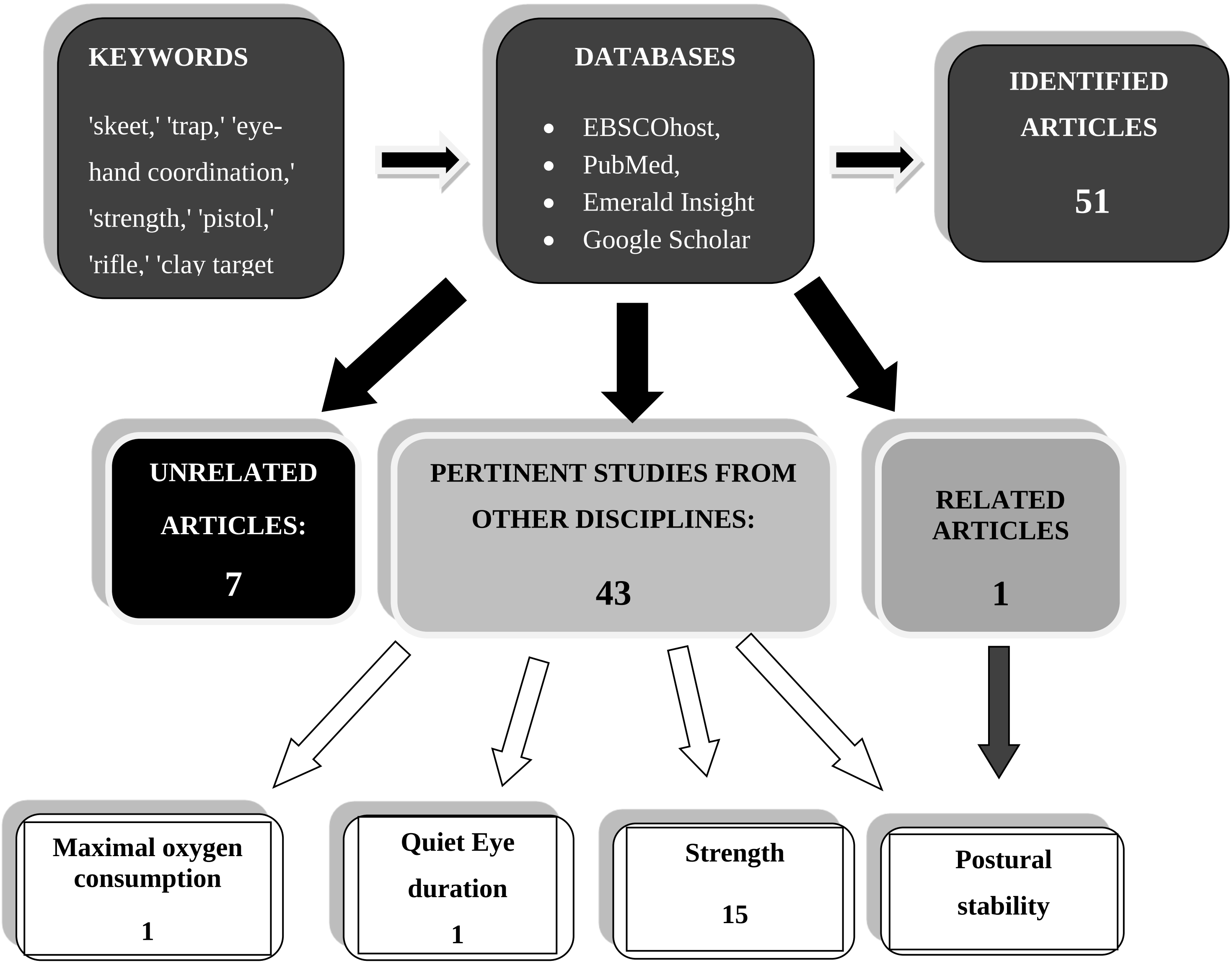


Figure 6: Study Flow Diagram

2.4 PERTINENT TRANSFER FROM STUDIES IN OTHER DISCIPLINES

Despite limited research explicitly conducted on Olympic clay target shooting, a considerable body of empirical studies exploring the significance of specific fitness parameters in other shooting disciplines exists (i.e. archery, pistol, and rifle). The investigations can be categorised into four main areas: (1) Postural stability, presented in 26 studies related to stationary shooting disciplines; (2) Strength, which was the focus of 15 studies examining rifle and pistol shooting; (3) Quiet eye duration, with one study exploring its impact on rifle shooting; and (4) Maximal oxygen consumption (VO_2 max), which was investigated in one empirical study, explicitly analysing the VO_2 max values of rifle shooters. Below, each domain of focus is explained in greater detail:

2.4.1 Postural Stability

According to Woollacott and Shumway-Cook (2002), postural stability is defined as the ability to control body positions for movement and balance, while balance, in biomechanical terms, refers to sustaining the vertical line from the centre of mass within the base of support with minimal postural sway (Shumway-Cook & Haller, 1988). Anderson and Plecas (2000) conclude that balance is primarily controlled by the engagement of the midsection and lower body muscles. Furthermore, Spaeth and Dunham (1921) proposed more than a century ago that core stability, attained through reflexive actions of the trunk muscles, plays a vital role in maintaining a static position and reducing body sway. Also, more recent studies in shooting sports suggest a positive correlation between good postural stability, balance, and shooting accuracy (Aalto et al., 1990; Ball et al., 2011; Bayati et al., 2016; Goonetilleke et al., 2009; Gulbinskienė & Skarbalius, 2009; Heimer et al., 1985; Kayihan et al., 2013; Koley & Gupta, 2012; Koley & Uppal, 2016; Konttinen et al., 1998; Konttinen et al., 1999; Mason et al., 1989; Mononen et al., 2007; Niinimaa & McAvoy, 1983; Pryimakov et al., 2015; Puglisi et al., 2014; Sattlecker et al., 2014; Stambolieva et al., 2015; Su et al., 2000; Zatsiorsky & Aktov, 1990). Notably, the single empirical study in this domain focused on clay target shooting by Puglisi et al. (2014) concluded that Skeet shooting performance benefits from better balance. The authors further recommend incorporating balance training into Skeet shooters' training routines. However, these results contradict many published studies in other shooting sports. For instance, Stuart and Atha (1990) examined archers and proposed that postural stability may not be the primary skill distinguishing elite performers from lower-level athletes in their sport. Similarly, Ihalainen et al. (2015) suggested that postural balance has an insignificant influence on air rifle shooting performance. Also, other authors have expressed opposition to the suggested positive link between postural stability and shooting performance, asserting that postural stability does not significantly influence shooting performance (Anderson & Plecas, 2000; Era et al., 1996; Zemkova, 2013). The contrasting results in the existing literature highlight the need for further investigation and clarification on the role of postural stability and balance in shooting sports, particularly for the Olympic clay target shooting disciplines.

2.4.2 Strength

Fifteen studies have been discovered in the scientific literature regarding the importance of muscle strength for more successful shooting performance. Several researchers have investigated the link between maintaining a steady firearm and forearm and shoulder strength (Mon et al., 2015; Pellegrini & Schena, 2005; Tang et al., 2008; Vercruyssen et al., 1988). In the comprehensive study of Vercruyssen et al. (1988), shoulder and hand grip strength training were introduced to air pistol shooters, which resulted in the expected strong correlations to strength performance. However, further analysis by the authors brought the most compelling results: improvements in the selected strength parameters also improved shooting performance. Also, Mon et al. (2015) identified positive correlations between finger flexion strength and performance in competitive pistol shooters. However, the same authors disagree with the findings of Vercruyssen et al. (1988), who demonstrated a strong correlation between shoulder abduction force and accuracy in air pistol shooting. In addition, no significant association was confirmed by Mon et al. (2015) between performance and anthropometric measurements (i.e. age, weight, height, or body mass index). Furthermore, after an intervention program on competitive shooters, Krasilshchikov et al. (2007) conclude that an increased level of balance has decreased sway and, combined with improved core strength, has positively affected aiming capacity. A more recent study by Sobhani et al. (2022) examined female pistol shooters and concluded that abdominal strength endurance was also associated with better performance, dynamic balance, and lower resting heart rate. Also, Kayihan et al. (2013) examined police academy cadets on the correlation between accuracy in pistol shooting and selected fitness parameters. According to the authors, there is a significant correlation between shooting performance and handgrip strength, as well as the posterior muscle chain's flexibility, balance, and coordination. Moreover, handgrip strength has been consistently linked to improved handgun shooting performance (Charles & Copay, 2003; Copay & Charles, 2001; Rodd et al., 2010; Vučković & Dopsaj, 2007). A further study by Evans et al. (2003) investigated the effects of upper extremity muscle fatigue during rifle shooting in an unsupported standing position. The authors proved that better-conditioned soldiers recover their shooting accuracy faster after intensive upper-body training. Comparable results were found by Ito et al. (2000) for the effect of aerobic exercise on rifle shooting accuracy, leading to the conclusion that an elevated level of physical fitness allows for rapid recovery of shooting accuracy after strenuous training. Furthermore, Hoffman et al. (1992) found that the intensity of physical exertion immediately before biathlon shooting impaired standing shooting accuracy by affecting stance stability but had only minor effects on prone shooting performance. In a different study, Koley and Gupta (2012) reported that dominant right handgrip strength positively correlates with upper arm circumference in contraction, height and weight.

In a hypothetical context, clay target shooters rely on isometric strength to maintain a stable stance and posture during their performance. Moreover, the dynamic rotational movement of the upper body while tracking the moving target further engages the muscles of the trunk and legs. This unique dynamic motion in shooting sports exerts additional strain on the shooter's muscular-skeletal system. Additionally, the arms, responsible for holding the weighty 4kg gun, remain unsupported, necessitating substantial static strength of the shoulder girdle, arms, hands, neck, abdominal and back muscles. Also, with each shot, powerful recoil exerts an enormous impact force (see Chapter 1), particularly on the dominant side of the shooter's upper body. Furthermore, the specific stance and body posture play a crucial role, as athletes slightly lean forward while mounting and following the target before executing the shot. This position leads shooters to apply more pressure on the front foot, accounting for approximately 60% of their weight distribution, thereby adding additional load on the core and posterior muscle chain. The given information necessitates an examination of the significance of muscle strength, particularly in the upper body, handgrip, and core, regarding performance in the Olympic clay shooting disciplines.

2.4.3 Quiet Eye Duration

According to Vickers (1996), the ‘Quiet Eye’ (QE) refers to the final fixation gaze directed at a target before initiating a planned motor response, representing a crucial cognitive processing phase in which the control parameters of a motor skill are programmed. Behan and Wilson (2008) argued that aiming accuracy is influenced by the duration of the QE period, with more extended QE periods being associated with superior performance. This statement was supported by Causer et al. (2010), who found a positive correlation between a longer QE duration and shooting accuracy in Skeet, Trap, and Double Trap athletes. However, it is essential to note that the QE duration is influenced by the performer's anxiety levels, with higher anxiety levels having a negative impact on gaze behaviour and QE (Causer et al., 2010; Janelle, 2002; Nian-Hong, 2003). Considering this relationship, several studies (Antunes et al., 2005; Cox et al., 2003; O'Connor et al., 1991; Petruzzello et al., 1991; Raglin & Morgan, 1987) have reported significant correlations between maximal oxygen uptake (VO_2 max) and anxiety. VO_2 max was defined initially by Hill and Lupton (1923) as the maximum oxygen uptake achieved during maximal exercise intensity, beyond which further increases in exercise workload cannot elevate it. Based on the studies indicating a positive association between low-stress levels and higher VO_2 max, it can be speculated that reducing anxiety levels through higher VO_2 max levels and incorporating activities like swimming and yoga (Berger & Owen, 1988) could potentially have a positive impact on QE duration and, in theory, enhance shooting accuracy. While QE is classified as a perceptual-cognitive ability (Moeinirad et al., 2020) and is beyond the scope of this study, the possible indirect effects of some physical fitness parameters (e.g. VO_2 max) on clay shooting accuracy through improvements in QE duration should be investigated.

2.4.4 Maximal Oxygen Consumption (VO_2 max)

The review of existing scientific literature revealed a single study conducted by Mondal et al. (2011), which demonstrated that the VO_2 max levels of rifle shooters were notably lower compared to international VO_2 max levels of swimmers, runners, basketball, and football players. The VO_2 max values of the examined shooters were comparable to those of competitors in athletic Field disciplines, specifically discus throwers and shot-putters. These results are unsurprising since shooting is not classified as an endurance sport (Kasapis & Thompson, 2009), and the average VO_2 max levels are considered sufficient for successful performance. However, Wells et al. (2009) showed that golfers with better aerobic endurance performed better than golfers with lower VO_2 max, although golf is also classified as a non-endurance sport (Kasapis & Thompson, 2009). While there is no empirical data in shooting sports addressing the impact of VO_2 max levels affecting stress and anxiety, and so indirectly affecting shooting accuracy, existing research in other fields has shown a clear link between higher VO_2 max levels and a reduction in both stress and anxiety. For example, Raglin and Morgan (1987) suggested that exercise and rest have similar effects on reducing anxiety and blood pressure and that the anxiety reduction effects of specific exercises have even longerlasting effects. Additionally, Petruzzello et al. (1991) noted that various forms of aerobic exercise were associated with anxiety reduction, and Antunes et al. (2005) provided data indicating that an aerobic exercise program introduced to elderly individuals had a positive correlation to anxiety and depression reduction. Similarly, Dustman et al. (1984) reported four decades ago significant improvements in the neuropsychological performance of inactive elderly individuals after a four-month aerobic exercise program. They suggested that the initiated aerobic training program enhanced brain metabolic activity, positively influencing the group's neuropsychiatric performance.

In conclusion, substantial evidence supports the notion that aerobic training can reduce anxiety, improve neurological performance, and positively affect shooting accuracy. While competitive clay target shooting does not necessarily require an elevated level of aerobic endurance, the given evidence supporting the benefits of aerobic training for reducing anxiety, improving neurological performance, and potentially enhancing shooting accuracy through improved cognitive function and fine motor control is vital to investigate the role of VO2 max levels in Olympic clay shooting.

2.4.5 Additional Studies

While conducting the literature review, multiple studies related to shooting sports were uncovered, but they had little to no relevance to the specific interests of my research. For example, the study by Lakie et al. (1995) investigated the effect of heating and cooling on air pistol shooters to reduce forearm tremors. Likewise, Kruse et al. (1986) examined the effectiveness of metoprolol, a β-blocker, in reducing hand tremors. Furthermore, Tang et al. (2008) explored hand tremors in pistol shooters, while Pellegrino and Schena (2005) utilised a laser pointer to measure tremors. Additionally, the study by Janelle and Hatfield (2008) details the findings of psycho-physiological assessments on the correlation between emotion and attention concerning motor task performance simulated in a laboratory setting or monitored in real-life competitive scenarios. While these studies may not directly align with the scope of the presented investigation, the examination by Lakie (2010) into the influence of temperature and exercises on tremors in Olympic biathlon athletes may offer some insights applicable to clay shooting. Also, the research conducted by Brown et al. (2013), which examined the shooting performance of police officers after exposure to physical exertion, could be of interest as it explored the impact of fatigue on shooting reaction. Furthermore, the timing of the trigger pull during rifle shooting in relation to the cardiac cycle, such as those by Helin et al. (1987), Konttinen et al. (2003), and Mets et al. (2007), may also offer relevant information. Moreover, in archery, rifle, and pistol shooting, a substantial body of empirical studies has been dedicated to the occipital electroencephalogram (EEG) alpha-power reactivity during shooting (Bird, 1987; Hatfield et al., 1984; Hatfield & Landers, 1987; Haufler et al., 2000; Janelle et al., 2000; Landers et al., 1994; Loze et al., 2001). Although the results of those studies are not directly applicable to clay target shooting, they highlight the significance of EEG alpha-power in shooting sports performance. Further, the study by Mohamed et al. (2014) investigated the capability of archers of different performance levels to regulate breathing, and the results revealed a significant correlation between the ability to control breathing and overall performance. Additionally, Fenici et al. (1999) examined the cardiovascular adaptations of athletes engaged in action shooting and the authors suggested that higher blood pressure and heart rate could potentially obstruct shooting accuracy. Although the presented research does not directly support the specific goals of this study, it provides valuable perspectives on different shooting sports areas, which opens a broader scope of inquiry in the future.

2.5 CONCLUSION

This chapter has covered objectives 1 and 2 by investigating the existing empirical research and theoretical explanations on the importance of physical fitness components in Olympic clay target shooting and relevant research from other shooting disciplines. Despite some guidelines in Section 2.3 regarding the significance of specific fitness parameters for the Skeet and Trap shooting disciplines, the research in this area remains insufficient. A comprehensive examination of the literature reveals a predominant focus on stationary shooting disciplines, leaving a noticeable gap in empirical studies concerning parameters that could directly or indirectly influence Olympic clay shooting performance. For instance, the effect of jaw and head positioning during shooting, which various authors have associated with postural stability (Baldini et al., 2013; Gangloff et al., 2000; Sforza et al., 2006), requires further exploration. Additionally, the relationship between postural stability and Quiet Eye duration and the potential stress reduction through increased levels of VO_2 max requests a deeper investigation. The assessment of competitive clay shooters' VO_2 max levels and the potential benefits of increasing these values for performance enhancement are imperative. Establishing optimal levels of VO_2 max and examining its significant impact on shooting accuracy should also be a priority. Postural stability emerges as one of the most studied fitness parameters in shooting sports, including a single study on competitive Skeet shooters by Puglisi et al. (2014). Its role and significance in enhancing accuracy in Olympic clay shooting disciplines necessitate further comprehensive exploration. Moreover, the importance of strength and strength endurance, especially upper body and handgrip strength, specific to clay shooting athletes, requires attention. The considerable weight of the shotgun and the repetitive recoil force experienced with each shot highlight the importance of handgrip and upper body strength endurance. Furthermore, the role of abdominal and posterior chain muscles in the specific stance and motion during the execution of the shot and their correlation with body sway and improved postural stability demands investigation. Evaluating flexibility and mobility, which are integral components of fitness assessments in various sports, should also be considered in the context of clay target shooting. In addition, reaction time is a distinct fitness component in clay target shooting compared to stationary shooting disciplines. The rapid response requires mounting, following and shooting at a target moving at up to 100km/h, which necessitates further empirical studies to understand its actual significance and optimal levels for successful performance. Additionally, basic anthropometric measurements of elite Skeet and Trap athletes should be compared to those of less successful shooters to explore potential influences on performance (e.g., height, weight, percentage of body fat). To enhance performance in the clay target disciplines, in-depth research in this field is essential. The scarcity of scientific work presented in Section 2.3 highlights the need for further investigations into Olympic clay target shooting. By conducting further research, we can enhance the understanding of the clay target shooting sport and effectively assess the essential fitness components, enabling us to develop sport-specific training programs that will provide for the distinct needs of Skeet and Trap athletes.

CHAPTER 3: Assessment of Physical Fitness Parameters in Olympic Clay Target Shooters and Their Relationship with Shooting Performance

3.1 INTRODUCTION

After examining objectives 1 and 2 in Chapter 2, an apparent dearth of scientific recommendations on the role of specific fitness components in Olympic clay shooting was highlighted. This subsequent investigation aimed to explore objective 3 by identifying the importance of selected fitness and anthropometric parameters for better performance of Olympic clay target shooting athletes. Being part of the Summer Olympic program, in the prestigious disciplines of Skeet and Trap, only two athletes per category (Skeet women, Skeet men, Trap women, Trap men, and Trap mixed team) qualify every four years for this most prestigious competition. Qualification requires achieving a Minimum Qualification Score (MQS) within a designated period determined by the International Shooting Sport Federation (ISSF). Additionally, specific competitions, such as the World Cup and European Cup, offer opportunities for athletes to earn Olympic spots based on their performance. Consequently, securing a significant international event victory with a qualifying spot and meeting the required MQS within the specified period ensures an athlete’s qualification for the Olympic Games. Countries and nations widely recognise the Olympic Games as an opportunity to enhance their international image, making it a popular event for athletes to participate in and win medals (Haut et al., 2018). Therefore, coaches and experts from various disciplines work meticulously to assist elite performers in achieving superior results, including applying innovative technologies to enhance biomechanical and technical understanding of the sport. However, this study focused on determining the fitness components that hold the utmost importance in Olympic clay shooting. Hawley and Burke (1998) concluded that shooting athletes should undergo physical conditioning to improve their skill execution. Yet, Chapter 2 revealed scarce recommendations regarding the significance of specific physical fitness components in this shooting sport. Thus, it is of great interest to place more emphasis on these factors to assess their potential in enhancing performance.

Although clay shooting may appear effortless to an inexperienced observer, it places significant psychosomatic demands on athletes during training, and particularly at competitions. Official tournaments' competitive pressure, duration, and structure impose substantial psychological and physical strains on clay shooting athletes. Each shot execution demands handling and energetically moving an approximately 4kg heavy shotgun, with a high number of repetitions being performed within a brief period (see Chapter 1). A typical competition round of twenty-five shots lasts fifteen to twenty minutes, with an approximately one-hour break between each round, spanning the five rounds over two or three days. To qualify for the final round of a top-class tournament, athletes usually must shoot successfully more than 120 targets out of the maximum 125. In other words, elite competitors can miss one clay target per round on average. Notably, the pressure of the competition, combined with its structure and duration, places significant physical demands on clay shooters (Mon-López et al., 2019), and just as stationary shooting sports have witnessed a fitness revolution recently (Hellström, 2017), clay shooting is also likely to benefit from similar advancements.

Consequently, there is a clear need for science-based recommendations on sport-specific conditioning. In particular, this study aimed to determine which parameters differentiate according to skill level and which fitness components, previously highlighted in the scientific literature as potentially crucial for performance in other shooting disciplines, might be applicable in this context for Olympic clay target shooting. Based on previous research in various shooting disciplines, it was hypothesised that specific parameters would significantly correlate with performance and show significant differences between shooters of different skill levels.

3.2 MATERIAL AND METHODS

3.2.1 Participants

For this study, nineteen members of the Cyprus Shooting Federation competing in the Olympic clay shooting disciplines (i.e., Skeet, n = 9, and Trap, n = 10) volunteered. Three athletes were female, and sixteen were male, with an average age of 28.7. Eleven athletes competed on a club level, with an average experience of 3.7 years and an average shooting score on the previous three competitions of 100/125. Eight athletes were national team members, competing on an international level with 7.1 years of experience and an average shooting score of 113/125. Four national team members reported working with a physical fitness coach. Before the examination, all participants signed an informed consent after reading the information sheet. The university's ethics committee (BAHSS518) approved the investigation in accordance with the Declaration of Helsinki's ethical principles for research involving human participants before conducting the study.

3.2.2 Procedure

In order to minimise the potential impact of fatigue on the outcomes of the tests, the assessment was performed in the following order: (1) reaction time, (2) postural stability, (3) flexibility of the posterior muscle chain, (4) shoulder mobility, (5) handgrip strength, (6) upper-body strength endurance, (7) trunk strength, and (8) cardiopulmonary fitness. Before each test, an appropriate warm-up routine was performed to prepare the participants adequately.

3.2.2.1 Shooting scores and anthropometrics

The height and mass were recorded after calculating and recording the average shooting score from the participants' last three official competitions. In addition, the body fat composition was measured using a single-frequency Body Fat Analyzer (BF-322, Tanita Corporation of America, Inc., USA) by following the instructor's manual.

3.2.2.2 Reaction time

Measuring reaction time to a visual stimulus was conducted using the Optojump laser system (Microgate, Italy), explicitly replicating the action during the call for the target and the movement of the gun from the "ready" position towards the target. To ensure accurate measurements, the positioning of the Optojump laser system was adjusted according to the participant's requirements, and they positioned their unloaded guns between the laser beams. A laptop was positioned 3 meters in front of the athletes. Upon the screen changing from black to green, the participants moved the gun freely in any chosen direction, simulating the act of firing at an actual clay target with set-up adjustments for the two disciplines (Figures 7 and 8). Diverse protocols were utilised for Skeet and Trap shooters, imitating the actual course of a shooting round, encompassing the time required to move between shooting stations and the number of stations from which the athletes shot, as previously detailed in Chapter 1. As a result, trap shooters underwent twenty-five trials with thirty-second breaks in between, while skeet athletes participated in nine trials with sixty-second breaks between each attempt. All trials' average reaction time score was employed to facilitate individual analysis. However, it should be noted that technical issues prevented two of the non-elite group members from completing the test. In addition, due to a busy training and competition schedule, the test was repeated with only five out of the preliminary 17 participants and has shown a high level of reliability ($r = 0.92$) using the interclass correlation coefficient (ICC 1/1) in the one-way random effects model.

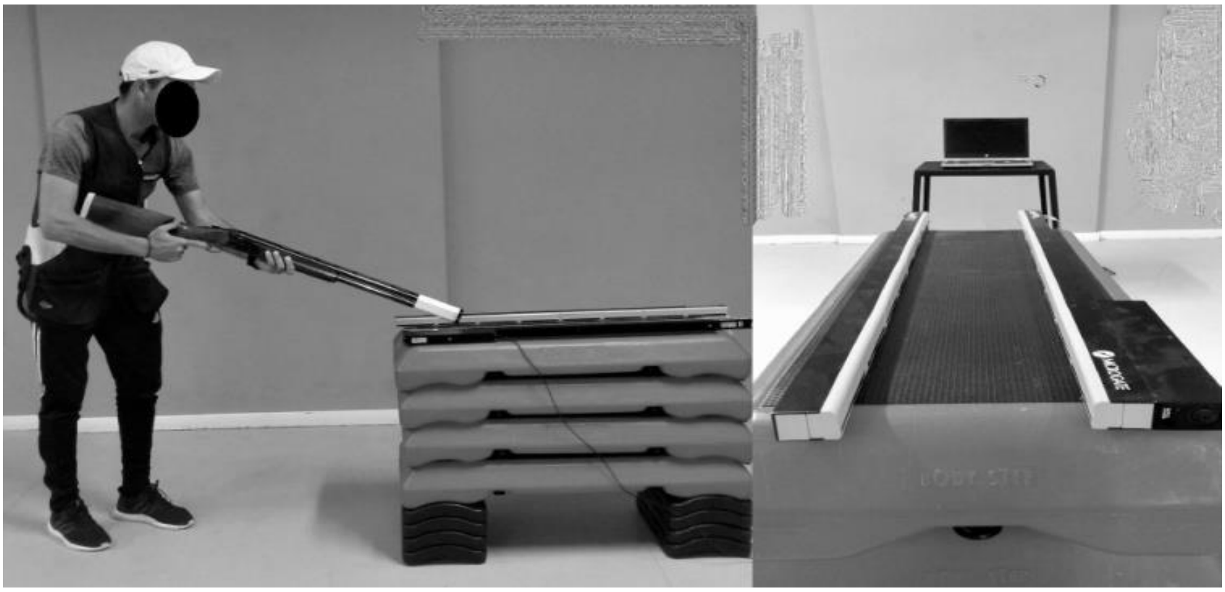


Figure 7: Skeet shooter set up with the shotgun positioned between the Optojump system prior to trial commencement (left). Optojump system positioned in line with the stimulus screen (right).

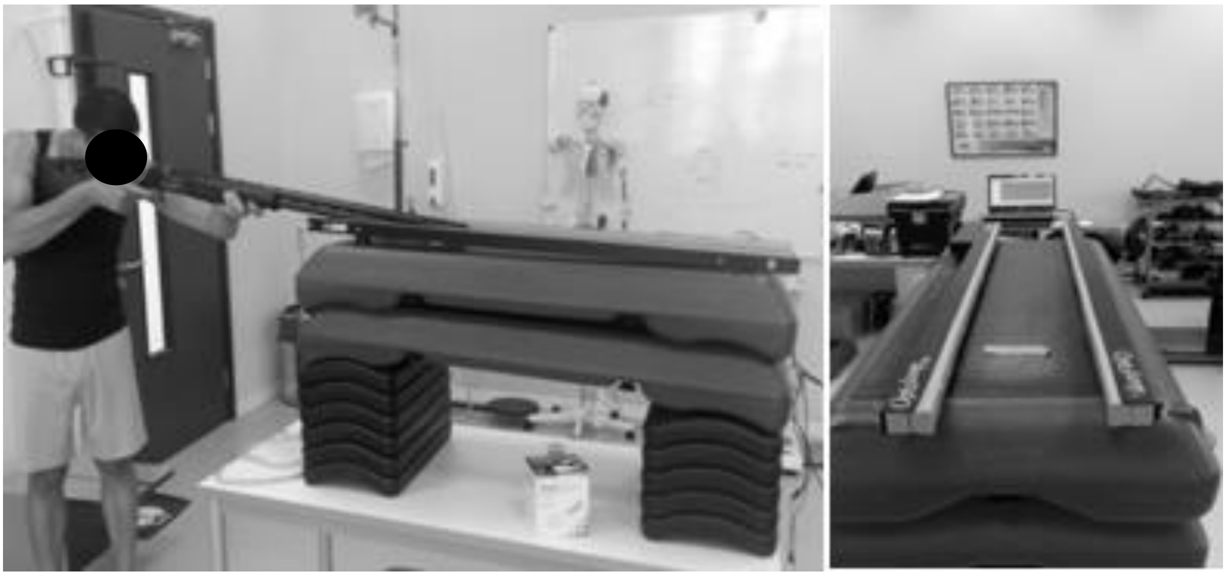


Figure 8: Trap shooter set up with the shotgun positioned between the Optojump system prior to trial commencement (left). Optojump system positioned in line with the stimulus screen (right).

3.2.2.3 Postural stability

The participants were asked to stand on a balance disc with their arms by their sides and wear the shoes they used during their shooting training and competition. The disc was mobile to all sides and part of the Coordi software (MFT Challenge disc, TST Trendsport, Austria), which provided instant feedback on the screen placed in front of the participant (Figure 9). The position of the disc, reflecting the participant's bilateral leg stability, was represented by a dot on the screen (Hildebrandt et al., 2015). A high test-retest reliability was reported by Müller et al. (2015), r = 0.91. All participants were tested on the software programme Level 3 and instructed to keep the small dot inside the larger dot on the screen. The participants got one familiarisation trial before performing the test, which consisted of dynamic and static balance challenges. The bigger dot was moving in different patterns during the dynamic balance testing. The participant had to alter her/his centre of mass accordingly to follow the movement of the bigger dot, attempting to keep the small dot within the larger dot's perimeter. During the static balance assessment, the dot was motionless, positioned in the middle of the screen for fifteen sec, and the participant had to try to keep the small dot still at the centre of the screen as long as possible. The participants' score from the maximum of one hundred points was recorded.

Figure 9: Positioning of the participant on the MFT Challenge disc (left). Screen showing the small dot which should be moved by the participant in the big (darker) dot by shifting the weight on the board (right).

3.2.2.4 Posterior muscle chain flexibility

The sit-and-reach test, known for its high test-retest reliability (r = 0.94, Johnson & Nelson, 1986), was employed to assess lower back and hamstring muscle flexibility. The test involved a standardized box with a marked heel line at twenty-three cm from the front. Participants were asked to sit barefoot in front of the equipment with fully extended knees and their heels against the front of the box. To ensure accurate results, the examiner placed one hand on the knees to prevent knee flexion during the investigation. Instructions were given to the participants to place their hands on each other, palms down, and then push their hands forward along the measuring tape as they bent forward. The trial was considered invalid if the hands were separated, if one hand was pushed significantly ahead of the other, or if the knees were bent during the movement. The distance reached during the forward stretch must have been held for 1-2 seconds to be valid. The best result from three trials was recorded to the closest centimetre, with a one-minute break between repetitions.

3.2.2.5 Shoulder mobility

This parameter was examined using the shoulder mobility test from the Functional Movement Screening (FMS), as introduced by Cook et al. (2014). Morgan et al. (2023) reported inter-rater reliability from good to excellent for this test (r = 0.85-0.94). Participants were asked to position themselves facing the wall and ensure that their toes were in contact with the wall to prevent leaning forward during the test. Subsequently, they were asked to form fists with both hands and extend their arms in front of their shoulders. Next, participants performed a reciprocal reaching pattern, in which one arm carried out an internal shoulder rotation while the other conducted an external shoulder rotation, moving from above. Participants were instructed to stop once they reached maximum reach and were discouraged from adjusting or moving their fists closer afterwards. Following each trial, a one-minute break was given, and finally, the smallest distance attained in centimetres was recorded. Upon completing three trials on one side, determined by the superior arm, the identical procedure was repeated on the contra-lateral side.

3.2.2.6 Handgrip strength

For the assessment of handgrip and overall body strength, a handgrip dynamometer (Grip D, T.K.K. 5401, Takei Scientific Instruments, CO., Ltd. Japan) was used, indicating an excellent level of reliability (r = 0.90, Adams, 1998). Participants were given clear instructions on using the dynamometer, ensuring that the gripping position was tailored to everyone's hand anatomy. This allowed for a comfortable and secure grip between the palm, the thumb's base, and the fingers' second phalange. During the execution of the test, the participants were instructed to slightly lean forward and flex the elbow as they were squeezing the apparatus for 2–3 seconds with maximum force. The test was performed three times for each hand, with a 3-minute rest interval between each attempt, ensuring sufficient recovery and minimizing fatigue-induced errors. Subsequently, the highest result for each hand in kilograms (kg) was recorded, reflecting the participants' maximum handgrip strength for analysis and comparison.

3.2.2.7 Upper-body strength endurance

The evaluation of the parameter involved administering a maximum push-up test, with its test-retest reliability established at a robust coefficient of (*r* = 0.93, Johnson & Nelson, 1986), signifying an elevated level of consistency in repeated measurements. Participants were given detailed instructions on how to complete the test correctly. They began the exam in the prone position, maintaining an upright position with hands shoulder-width apart and shoulders flexed. The primary movement involved pushing themself up from this position until the arms were fully extended. Throughout the test, participants were instructed to maintain a firm body posture with a straight back and ensure proper alignment. In the lower position of each push-up repetition, participants were expected to touch a 5 cm high sponge under their sternum to ensure adequate depth of the movement. If a participant failed to touch the sponge or fully extend their elbows during a repetition, that repetition was considered invalid and not counted. A modified test version was used for female participants, in which knee push-ups were performed. In this variation, the participants placed their hands shoulder-width apart and supported their lower body on their knees. The number of correctly performed push-ups was recorded, with no rest permitted between repetitions, to ascertain the individual's maximum capacity for push-up performance.

3.2.2.8 Trunk flexion/extension strength

The evaluation of trunk flexion/extension strength was conducted employing an isokinetic dynamometer, specifically the HUMAC/NORM^{TM} Testing & Rehabilitation System (Computer Sports Medicine Inc., USA), which was reported by García-Vaquero et al. (2020) to have a high-to-excellent intra-class correlation coefficient (*r* > 0.74). Given the specific body position and action during Olympic clay shooting, the participants were positioned on the trunk extension/flexion (TEF) modular component in a standing posture. The axis of rotation was carefully set at the intersection point of the mid-axillary line and the lumbar-sacral junction, as per the protocol outlined by Yoo et al. (2014). The range of motion for the TEF test was defined from -8° (flexion) to 60° (extension). Before the formal assessment, participants engaged in four maximal warm-up repetitions, followed by four maximal test repetitions at an angular velocity of 60°/s. Subsequently, the same sequence was repeated at a higher angular velocity of 120°/s. To minimize fatigue's effects, a standardized rest period of 60 seconds was provided between each set. The outcome measures focused on the peak torque (PT) obtained from the isokinetic muscular function at both 60°/s and 120°/s, specifically for trunk flexion and extension. The recorded results provided a valuable assessment of the participants' trunk strength under controlled movement conditions.

Figure 10: Participant positioned on the trunk extension/flexion (TEF) modular component in a standing posture on the HUMAC/NORM™ Testing & Rehabilitation System

3.2.2.9 Cardiopulmonary fitness

The assessment of maximum oxygen consumption (VO_2 max), an incremental treadmill method with a modified Heck protocol, was used. The examination was conducted by applying the Cosmed Quark cardiopulmonary exercise test system (CPET, Rome, Italy), which uses breath-by-breath analysis for accurate gas exchange measurements (Nieman et al., 2013). Throughout the testing procedure, the environmental conditions in the laboratory were maintained at 22 ± 1 ºC, and the relative humidity levels at 50%. The treadmill's incline was consistently set at 3% during the warm-up and test phases. During the warm-up, the speed started at 4.8 km/h and increased by 1.2 km/h every 1 min for 3 min, while during the test phase, the speed started at 8.4 km/h and increased by 1.2 km/h every 2 min until exhaustion. The test was completed once the VO_2 levels remained constant or reduced with an increased workload or when the participants had reached volitional exhaustion. During the cool down, the recovery speed was abridged to 4.8 km/h and remained steady for 3 min with zero inclination. Regarding VO_2 max determination, for all participants except one member of the elite group who was unable to participate due to injury, the highest recorded VO_2 max value sustained for an average of 10 seconds was identified as their VO_2 max level, indicating their maximum capacity for oxygen consumption.

3.3 STATISTICAL ANALYSIS

In the comprehensive evaluation of the examined fitness parameters, anthropometric variables, and the average of the last three official shooting scores, descriptive statistics were employed to calculate the mean values and their corresponding standard deviations (mean ± *SD*). Subsequently, statistical analysis was conducted using SPSS v25.0 (SPSS Inc., Chicago). To ensure the appropriateness of the statistical tests, data normality was assessed through the Shapiro-Wilk test, adopting a significance level of $p < 0.05$. Additionally, Brown and Forsythe's test was utilized to verify the homogeneity of variance. The examination of correlations between fitness variables, anthropometric measures, and outcome scores for the entire participant group was executed through bivariate correlation analysis. Pearson-product moment correlation coefficients were applied to measure the strength and direction of the associations between the variable scores and the average of the recent official shooting scores. Participants were categorized as elite (national team members) and non-elite shooters, and independent-sample t-tests were employed, using a significance level of $p < 0.05$ to determine statistical significance to ascertain the distinctions in fitness and anthropometric qualities. Furthermore, to measure the effect sizes of the observed differences, Cohen's d was calculated and categorized as small (0.2), medium (0.5), or large (0.8), following the classification by Cohen (1992). Additionally, 95% confidence intervals were computed for each comparison, providing further insight into the precision and reliability of the effect size estimates.

3.4 RESULTS

Descriptive statistics (mean ± *SD*) by group and the entire sample are shown in Table 1 for shooting score, anthropometric data, and all tested fitness parameters.

Table 1: Shooters' Anthropometric and Fitness Test Results.

Variables	Elites	Non-Elites	Overall
	M ± *SD*	*M* ± *SD*	*M* ± *SD*
	Anthropometric Measures		
Height (cm)	170.3 ± 6.0*	178.2 ± 6.3*	174.8 ± 7.2

Mass (kg)	65.9 ± 14.5*	86.6 ± 20.2*	77.9 ± 20.5
BMI (kg/m^2)	22.5 ± 3.7	27.4 ± 6.7	25.3 ± 6.1
Body Fat (%)	18.3 ± 5.5	22.9 ± 8.6	21.0 ± 7.6
Fitness Measures			
Reaction Time (s)	0.40 ± 0.054	0.40 ± 0.034	0.40 ± 0.043
Dynamic Balance (points out of 100)	40.6 ± 7.2*	30.7 ± 6.7*	34.9 ± 8.4
Static Balance (points out of 100)	64.1 ± 16.6*	40.9 ± 17.8*	50.7 ± 20.5
Flexibility of the posterior muscle chain (cm)	36.4 ± 6.6*	23.8 ± 5.6*	29.1 ± 8.7
Left Shoulder Mobility (cm)	16 ± 4.6	21.5 ± 7.1	19.2 ± 6.7
Right Shoulder Mobility (cm)	15.8 ± 5.6	16.0 ± 7.6	15.9 ± 6.6
Difference between R/L Shoulder Mobility (cm)	2.3 ±2.5	4.6 ± 4.5	3.6 ± 3.9#
Right Handgrip (kg)	46.3 ± 12.3	48.7 ± 6.4	47.7 ± 9.1
Left Handgrip (kg)	43.2 ± 12.5	43.9 ± 6.5	43.6 ± 9.2
R/L Grip Difference (kg)	3.8 ± 2.4	4.8 ± 4.2	4.4 ± 3.5#
Max Push-up (repetitions)	28.6 ± 12.1	22.2 ± 11.6	24.9 ± 12.0
Trunk Flexion at 60 °/s (Nm)	189.5 ± 50.3	217.5 ± 39.8	205.7 ± 45.4
Trunk Extension at 60 °/s (Nm)	241.4 ± 85.0	232.2 ± 47.0	236.1 ± 63.7
Trunk Flexion at 120 °/s (Nm)	150.0 ± 48.6	155.7 ± 87.5	151.9 ± 58.3
Trunk Extension at 120 °/s (Nm)	155.7 ± 54.6	126.0 ± 65.0	145.8 ± 56.0
VO_2 max (ml/kg/min)	44.4 ± 7.9	41.2 ±11.7	42.5 ± 10.2

*Indicates a significant difference between the group scores. #Indicates a significant correlation between the variable and overall performance score.

Pearson product-moment correlation coefficients were found to be non-significant ($p > 0.05$) between height ($r = -0.19$, $p = 0.48$), mass ($r = -0.46$, $p = 0.063$), BMI ($r = -0.46$, $p = 0.062$), body fat ($r = -0.37$, $p = 0.14$), dynamic balance ($r = 0.34$, $p = 0.18$), static balance ($r = 0.12$, $p = 0.65$), posterior muscle chain flexibility ($r = 0.40$, $p = 0.11$), right shoulder mobility ($r = 0.42$, $p = 0.10$), left shoulder mobility ($r = 0.25$, $p = 0.34$), right handgrip strength ($r = -0.26$, $p = 0.32$), left handgrip strength ($r = -0.02$, $p = 0.95$), upper-body strength endurance ($r = 0.15$, $p = 0.58$), trunk flexion at 60°/s ($r = -0.41$, $p = 0.11$), trunk extension at 60°/s ($r = -0.25$, $p = 0.33$), trunk flexion at 120°/s ($r = -0.20$, $p = 0.64$), trunk extension at 120°/s ($r = -0.32$, $p = 0.44$), cardiopulmonary fitness ($r = 0.29$, $p = 0.28$) and mean shooting score. However, after the initial results did not show any significant correlations between the selected fitness parameters and shooting success, the investigation was extended to connections not previously investigated in shooting sports. The difference in bilateral symmetries of the two parameters to the performance levels was examined. The results revealed (a) strong correlations among better symmetry between the right and left shoulder mobility with performance score ($r = 0.80$, $p < 0.001$), (b) bilateral symmetry in handgrip strength had a significant relation with score ($r = 0.61$, $p = 0.01$). In addition, the two parameters examining upper-body asymmetries showed a noteworthy moderate correlation between them ($r = 0.55$, $p = 0.02$). Further, the results of independent-sample *t*-tests revealed several differences between elite and non-elite shooters. A significant disparity was observed for height ($t(17) = -2.76$, $p = 0.01$; $d = 1.29$, 95% CI [172, 178]), mass ($t(17) = -2.47$, $p = 0.03$; $d = 1.85$, 95% CI [68.7, 87.1]), posterior muscle chain flexibility ($t(17) = 4.46$, $p < 0.001$; $d = 2.04$, 95% CI [25.2, 33]), dynamic ($t(17) = 3.09$, $p = 0.01$; $d = 1.43$, 95% CI [31.1, 38.7]) and static balance ($t(17) = 0.3$, $p = 0.01$; $d = 1.35$, 95% CI [41.5, 59.9]), all with large effect sizes. In addition, the examination identified that national team members were shorter, lighter, and possessed better dynamic and static balance than non-elite shooters.

3.5 DISCUSSION

More than four decades ago, Corbin and Noble (1980) concluded that possessing a specific type of fitness positively affects performance in a physical activity or sport. Competitive clay target shooting is not an exception and requires distinctive physical qualities as this activity puts unique psychosomatic pressure on the athletes. However, it is still being determined if clay shooters develop these qualities because of the particular action or if they choose the specific activity because they already own these unique features—the present exploratory study aimed to identify performance factors among the tested parameters. Specifically, the research focused on the examined fitness components correlated strongly to clay shooting success. The presented examination wanted to establish (a) which physical fitness parameters discovered by previous literature as potentially necessary within the Olympic clay shooting disciplines were associated with current shooting scores, as well as (b) which parameters can differentiate based on skill level in the sport. Although it was revealed in Chapter 2 those previous examinations in other shooting sports established links for some fitness parameters with shooting success, this examination has not shown any noteworthy direct correlation of the selected parameters to performance in the Skeet and Trap disciplines. Similar results were reported by Yapici et al. (2018) when studying rifle shooters competing in the Turkish

Championship. The authors revealed no noteworthy correlation between shooting performance and flexibility, dynamic balance, reaction time, VO_2 max or respiratory function parameters.

However, further examination of the results found that better bilateral symmetry, specifically in shoulder mobility and grip strength, was strongly associated with higher shooting scores. In addition, skill level groups were differentiated based on factors such as height, mass, flexibility of the posterior muscle chain, and static and dynamic balance, with elite performers being lighter, shorter, and having better flexibility and balance. When considering the established performance factors, it is appealing that the two parameters significantly related to performance had (1) not been examined previously within shooting sports and (2) correlated to symmetric and not absolute values. From an interdisciplinary standpoint, asymmetry may also have a negative effect from the incapability to perform contra-lateral body fragments as a coherent whole and in the most efficient way, as pointed out by Carson and Collins (2016). Therefore, it could be suggested that clay shooting athletes are not limited to or benefit from any pre-existing fitness levels. Moreover, the results showing the considerable difference, compared to existing literature, should be taken into consideration, as several do seem to offer promise for future examination (e.g., flexibility and balance), even though some may be deceptive (i.e. height and mass) since all female participants in this study were elite performers. As presented in Chapter 2, Kayihan et al. (2013) examined the correlation between posterior muscle chain flexibility and shooting performance in police academy recruits. They showed a strong association between better hamstring, back flexibility, and handgun shooting accuracy. Based on these findings, the presented investigation examined posterior chain muscle flexibility. Still, it did not find a significant correlation with efficiency in clay target shooting, and the results are consistent with that of Yapici et al. (2018), who found no significant relationship between posterior chain flexibility and shooting performance in rifle shooters.

Given the technical differences between pistol and rifle shooting and competitive shotgun shooting, particularly that clay shooters hold the gun with both hands when aiming and following fast-moving targets, it seemed appealing to examine their shoulder mobility. Considering the constant strain on the shoulder girdle during the shooting action, in addition to repetitive and powerful recoils, provided sufficient ground to examine this parameter in more detail. More restricted shoulder mobility was expected to impact performance negatively, and better shooters would have a greater range of motion in this joint. However, the results did not confirm this hypothesis. Instead, they found that elite performers had smaller bilateral differences in mobility, suggesting that better neuromuscular balance in the shoulder girdle has a significant positive correlation to performance. This is a new insight into the importance of parameters that examine bilateral differences that may affect performance and prompts further research in this area of Olympic clay shooting. Furthermore, the second parameter significantly associated with performance was the difference in grip strength. Again, not absolute values differentiate performance levels, but bilateral differences. Although grip strength and finger muscle strength are essential for better pistol shooting performance (Kayihan et al., 2013; Mon et al., 2015; Vercruyssen et al., 1989), this could not be confirmed in the presented study. The reason for this could be traced to the fact that competitive pistol shooters primarily rely on their dominant hand during shot execution and perform the action from a static position into a stationary target, while in contrast, clay shooters hold the shotgun with both hands to perform a dynamic movement when shooting at a fast-moving target (see Chapter 1). However, the fact that the level of bilateral symmetry has shown a strong and significant association with clay shooting performance is noteworthy and indicates that the participant sample did not lack strength for the task, regardless of their gender and different skill levels. The indication that elite clay shooters have notably greater upper-body symmetry is novel information and a new aspect for future sports developments. It could be speculated that particular strength and flexibility asymmetries can negatively impact body control movements, as suggested by Grygorowicz et al. (2010). Various authors performed extensive investigations focusing on the effects of asymmetry on whole-body movements in a range of sports (e.g., Sanders, 2013). In addition, Knapik et al. (1991) conclude that asymmetries were significantly related to athletic injuries. Also, a more recent review by Maloney (2018) suggests that performance can be improved with specialized asymmetry correction training in sports such as soccer, swimming, and track and field. Moreover, the same author further argues that the weaker, deficient side may be more receptive to corrective training (Daneshjoo et al., 2013). It is unknown what injuries or performance deficiencies could be created by clay-shooting athletes because of various asymmetries. Further research is required into potential associations of various neuromuscular asymmetries to physical characteristics, motor control, and, most importantly, the possible impact on technique and performance in competitive clay shooting.

3.6 CONCLUSION

In this Chapter, Objective 3 was investigated by examining selected fitness parameters in correlation to clay shooting performance based on the findings and recommendations in Chapter 2. The primary purpose of this exploratory study was to identify performance factors in Olympic clay target shooting and investigate the potential influence of selected fitness components on shooting success. A significant finding in Section 3.4 was the strong association between more excellent symmetry in bilateral shoulder mobility and handgrip strength with higher shooting scores. Additionally, height, mass, posterior muscle chain flexibility, and static and dynamic balance were observed to differentiate skill level groups. Notably, the two parameters significantly related to shooting performance had not been previously examined within shooting sports and were found to correlate with symmetric rather than absolute values. The indication that elite Olympic clay shooters display notably greater upper-body symmetry presents a novel aspect for future sports developments. As observed in other sports, specific strength and flexibility asymmetries may negatively affect body control during movements (Maloney, 2018). Prior research has linked asymmetries to athletic injuries and suggested that specialized asymmetry correction training can enhance performance in certain sports (Sanders, 2013). However, the impact of asymmetries on clay shooting athletes necessitates further investigation, specifically into potential associations with physical characteristics, motor control, and overall shooting technique and performance. The findings suggest that pre-existing fitness levels may not limit or disadvantage clay shooting athletes. However, the considerable disparity compared to existing literature should be carefully considered, mainly as specific parameters, such as flexibility and balance, appear promising for future investigation. Notably, caution is necessary in interpreting results such as height and mass due to the influence of all elite female performers within the study sample. Further research is needed to explore the potential impact of fitness components on clay shooting success and to enhance our understanding of the complex interplay between sport-specific physical fitness and shooting accuracy in this sport. In conclusion, this chapter provides novel insights into performance optimization for Olympic clay target athletes and lays the foundation for further scientific exploration in this domain. The significance of bilateral symmetry concerning shooting performance and the potential implications of asymmetries give reason for further investigation. Identifying promising fitness parameters gives a base for future research undertakings in this sport.

CHAPTER 4: Assessment of Psychological and Psycho-Motor Parameters in Olympic Clay Target Shooters and their Relationship with Shooting Performance

4.1 INTRODUCTION

The pursuit of excellence in Olympic clay target shooting, like any other competitive sport, demands a comprehensive understanding of the factors influencing an athlete's performance. While in Chapter 3, the impact of selected fitness components on shooting performance was investigated, an equally important aspect that needs further investigation in this field is the role of psychomotor and psychological parameters. This chapter examines objective 4, the complex connections between psychomotor and psychological parameters and the success in Olympic clay shooting. One of the unique challenges of competitive clay target shooting is the close competition score, where the difference between qualifying for the finals and a medal or fourth place can be minimal. It is common at clay shooting competitions for athletes to achieve identical scores during the qualifying rounds or even in finals and to proceed to shoot-offs, sometimes even to determine the gold or bronze medallist. Such circumstances add to the already high psychosomatic demands on the athletes, where even the slightest pressure can negatively affect performance (Coleman, 1980). Additionally, it is essential to understand the different mental and physical demands during Trap and Skeet shooting performances. Because targets in the Trap discipline move unpredictably in any of three possible directions, shooters must make split-second decisions and adjust their movements and strategies. In Skeet shooting, by contrast, the direction of the target fired from two "houses" is known in advance (see Chapter 1). Therefore, the mental challenges are slightly different between the two disciplines, as Coleman (1980) concluded. Previous studies by Prapavessis and Grove (1991) emphasized the importance of individual assessments and intervention procedures tailored to the unique characteristics of clay shooters to enhance their performance. Furthermore, the authors emphasized the importance of assisting athletes in cultivating and maintaining their optimal performance mood state during competitions. Although there have been some scientific examinations into the field of psychology in clay target shooting (Causer et al., 2011; Rossi & Zani, 1991; Prapavessis & Grove, 1991), the existing research has been primarily reliant on subjective self-reporting (Ong, 2015). The popularity of self-reporting procedures has been linked to their cost-effectiveness and fast and straightforward administration (Baumeister et al., 2007). However, such methods have limitations, promoting exploring alternative approaches for more comprehensive assessments.

To overcome the restrictions of traditional measurement methods and further explore the psychological profiling of clay shooting athletes, the presented study included validated computerized tests besides conventional self-reporting assessments. The recommendations of previous authors encouraged the employment of computerized tests for the presented study (Ong, 2015; Zhu, 2012). For instance, Ong (2015) highlighted the enormous potential of technology-based assessments in evaluating various psychological aspects of athletes, including stress and motivation. As a result, this study combined two conventional self-reporting questionnaires and a computerized assessment tool for determining the psychomotor abilities of the examined clay shooters. More precisely, the modified Competitive State Anxiety Inventory (CSAI-2), recognized as a standardized assessment tool for state anxiety levels (Martens et al., 1990) and the Athlete Coping Skills Inventory (ACSI-28), measuring cognitive and somatic anxiety, self-confidence levels, and essential coping skills (Smith et al., 1995), were applied for this study. Additionally, six tests from the Vienna Test System (VTS) developed by Schuhfried GmbH were utilized for this study. The VTS is well-known for its validity and reliability in sport psychology assessments (Ong, 2015). Experts have extensively employed the VTS for psychological evaluations of athletes in various sports, but until now, its application in clay target shooting has remained unexplored. The presented study attempts to explicate to what extent psychological and psychomotor parameters are related to performance in Olympic clay target shooting. It was hoped that unique and new insights delve into the relationship between the psychomotor state of clay-shooting athletes and their ability to perform well in challenging and competitive situations. By using both computer-based testing and traditional self-report measures, this study aims to contribute to the field and lay the foundation for future exploration in this area.

4.2 METHODS

4.2.1 Participants

Nineteen members of the Cyprus Shooting Federation who participated in the examination presented in Chapter 3 took part in the study after reading the information sheet and signing the informed consent form. Prior to conducting the investigation, the study was approved by the University Ethics Committee (BAHSS518) in accordance with the ethical principles for research involving human participants in the Declaration of Helsinki. Participants in this study were three women and sixteen men (Mage = 28.7 years, *SD* = 11.3) as described in Section 3.2.1. Performance levels ranged from club-level competitors (*n* = 11) with 3.7 years of experience to highly skilled members of the Cyprus national team (n = 8) with an average of 7.1 years of experience. Additionally, six participants from the elite group reported working with a sports psychologist.

4.2.2 Procedure

The data collection process took place during a single 90-minute session and consisted of several sequential steps to evaluate the psychological and psycho-motor parameters of the participants systematically. At first, information regarding the average shooting scores in the previous three competitions was recorded. This data served as an essential baseline measure of the shooter's recent performance levels compared with their psychological and psycho-motor assessments. Subsequently, the CSAI-2 was administered to assess the participant's competitive state anxiety levels. The CSAI-2 is a well-established tool designed to estimate the individual's anxiety experienced in competitive conditions (Martens et al., 1990). This inventory incorporates three subscales, namely cognitive anxiety, somatic anxiety, and self-confidence, providing a comprehensive evaluation of the participants' anxiety states during competitions. Next, the ACSI-28 was provided to the participants to assess cognitive and somatic anxiety, essential coping skills and self-confidence. At last, five selected tests from the VTS were employed to measure various psycho-motor parameters. The use of the VTS aimed to expose essential aspects of the participant's cognitive and motor skills. The tests were chosen based on their relevance to the specific demands of Olympic clay target shooting, and they were expected to provide valuable insights into the shooters' decision-making abilities, cognitive processing speed, intentional focus, and motor coordination during clay target shooting.

4.2.2.1 CSAI-2

This section presents the modified version of the Competitive State Anxiety Intensity (CSAI-2), which was developed by Martens et al. (1990). The modified version of the CSAI-2 is an updated form of the original, created to address its limitations and improve its applicability and accuracy. This questionnaire is widely used in sports psychology to assess athletes' pre-performance cognitive anxiety, somatic anxiety, and self-confidence. For this study, the modified version, featuring nine items in each subscale, was utilized. The participants were asked to rate the intensity of the symptoms associated with anxiety and self-confidence. The response scaled from 1 (not at all) to 4 (very much so). The modified CSAI-2 helped to understand how the participants experienced cognitive and somatic anxiety, as well as their level of self-confidence before engaging in competitive shooting. The scores obtained from this assessment ranged from 9 to 36 for each subscale, enabling a comprehensive assessment of the intensity and direction of anxiety and self-confidence among the tested participants.

4.2.2.2 ACSI-28

In addition, the Athlete Coping Skills Inventory (ACSI-28) by Smith et al. (1995) assessed various coping skills in response to stressors and challenges frequently experienced in competitive sports. The ACSI consists of seven subscales, each focusing on specific coping strategies and mental qualities that add to an athlete's response to adversity and pressure: (1) Coping with Adversity, evaluated the extent to which an athlete remains positive, enthusiastic, calm, and controlled, even in the face of unfavourable circumstances. It also assessed the individual's ability to overcome mistakes and setbacks, demonstrating resilience and mental strength. (2) The Coachability subscale measured the athlete's openness to instruction and feedback from coaches. It also measured whether the participant could deal with constructive criticism without taking it personally and becoming upset, displaying a willingness to learn and improve. (3) The Concentration subscale examined the athlete's ability to maintain focus and concentration during practice and competitions. It assessed how distractions could influence the athlete's performance and how effectively they could refocus their attention. (4) Confidence and Achievement Motivation explored the athlete's self-belief and positive motivation. It assessed the individual's consistency in manifesting dedication to improve skills and display constant effort during practice and competitions. (5) Goal Setting and Mental Preparation, evaluated the athlete's capacity to set specific performance goals, mentally prepare for competitions, and develop a clear game plan and strategy. (6) Peaking under pressure investigated whether the athlete perceived pressure situations as challenges or threats. It examined the participant's ability to perform well under pressure, demonstrating composure and adaptability. (7) The Freedom from Worry subscale measured the extent to which athletes exert pressure on themselves by worrying about making mistakes or performing poorly. It also assessed whether the participant was concerned about the opinions of others regarding their performance.

4.2.2.3 VTS

Five Vienna Test System (VTS) tests were selected to evaluate the participants' psycho-motor and cognitive capabilities (Figure 11). These tests aimed to assess essential aspects of visual-motor coordination, attention focus, anticipation, reaction speed, and personality traits, providing valuable insights into the psychological profiles of the athletes. The following tests were employed in this examination: (1) Two-hand coordination evaluated the participants' eye-hand coordination, hand-hand coordination, and the synchronization of movements between the left and right hand. Fine motor skills and the extent of the visual-motor constructive interaction were assessed, both potentially important for aiming accuracy during clay shooting. (2) Signal Detection offered valuable insights into the athletes' capacity to maintain attention and respond effectively to relevant stimuli by determining the participants' long-term attention and ability to distinguish a relevant signal from distracting stimuli. Given the dynamic actions and focus required in clay target shooting, constant focus and accurate target identification, this is an essential test to be explored and related to successful performance. (3) Time-movement anticipation provided information regarding the participants' perceptual and motor anticipation skills by focusing on estimating the speed and direction of moving objects. In clay shooting, where targets move fast and sometimes unpredictable, the ability to anticipate and react quickly to changing trajectories is crucial. (4) Reaction Time measured the participants' ability to react fast under a simple stimuli scheme. In clay target shooting, the window of opportunity for successful target engagement and shot execution is limited and requires quick decision-making and motor responses. (5) Big Five Structure Inventory. Apart from psycho-motor and cognitive assessments, the study also explored the participants' personality traits by investigating five basic personality dimensions (i.e., emotional stability, extraversion, openness, conscientiousness, and agreeableness). Understanding the athletes' personality traits could offer supplementary insights into their emotional responses, interpersonal dynamics, and coping mechanisms, which may influence their overall shooting performance.

Figure 11: Vienna Test System (VTS)

4.3 DATA ANALYSIS

After collecting all the data, statistical analyses were conducted to examine the associations between the average shooting scores, CSAI-2 (Competitive State Anxiety Inventory-2) and ACSI-28 (Athlete's Coping Skills Inventory-28) scores, and the results obtained from the VTS. The data analysis process included correlation analyses to identify potential relationships between psychological and psychomotor parameters and shooting performance. SPSS v25.0 (SPSS Inc., Chicago) was used for all statistical analyses, and the data were checked for normal distribution using the Shapiro-Wilk test with an α-level of 0.05. The homogeneity of variance was verified using Brown and Forsythe's test. Bivariate correlation analysis was used to compare correlations among pairs of variables for the entire group. Pearson product-moment correlation coefficients were calculated among the results of the tested variables and the mean shooting score.

Participants were categorized into two groups: elite shooters (national team members) and non-elite shooters (club level). Additionally, independent-sample t-tests were conducted to compare the means of the two groups, with a significance level set at $p < 0.05$ to determine statistical significance in the differences observed in psychological and psychomotor qualities. To further assess the magnitude of these differences, Cohen's d was calculated, with effect sizes classified as small (0.2), medium (0.5), or large (0.8), based on Cohen's (1992) guidelines. Additionally, 95% confidence intervals were computed for each comparison, offering greater insight into the precision and reliability of the effect size estimates.

4.4 RESULTS

The Pearson product-moment correlation coefficients were found to be significant only for Coping with Adversity, with an *r*-value of 0.64, indicating a strong positive correlation, and an associated p-value of 0.04. No other parameters were found to be significantly associated with performance outcomes in this sample of athletes.

Table 2: Bivariate Correlation Analysis of Psychological and Psychomotor Parameters with Shooting Performance

	r	***p***
Coping with Adversity*	0.64	0.04
Cognitive Anxiety	0.05	0.70
Somatic Anxiety	0.04	0.73
Self-Confidence	0.15	0.12
Coachability	0.06	0.68
Concentration	0.07	0.63
Confidence and Achievement Motivation	0.08	0.61
Goal Setting and Mental Preparation	0.03	0.80
Peaking under Pressure	0.12	0.24
Freedom from Worry	0.14	0.16
Two-hand Coordination	0.05	0.71
Signal Detection	0.09	0.52
Time-movement Anticipation	0.07	0.60
Reaction Time	0.11	0.30
Emotional Stability	0.04	0.75
Extraversion	0.06	0.66
Openness	0.10	0.40
Conscientiousness	0.03	0.78
Agreeableness	0.09	0.55

*Indicates a significant correlation between the variable and shooting performance

Further, the results of independent-sample *t*-tests revealed a lack of statistically significant differences between elite and non-elite shooters. All results have a *p*-value greater than 0.05, indicating that the observed differences are likely due to random chance rather than a true effect. Specifically, the *t*-values ranged from 0.15 to 0.59, and the corresponding p-values ranged from 0.56 to 0.88. Additionally, the effect sizes were all small, ranging from 0.06 to 0.15, indicating that even if a true effect existed, it was small. The 95% confidence intervals for these effect sizes all included zero, further indicating that the differences between the groups were not statistically significant.

Table 3: Results of the Independent t-Test Comparing Psychological and Psycho-Motor Parameters with Shooting Performance

	t(19)	*p*	d	95% CI
Cognitive Anxiety	0.34	0.74	0.15	[-0.28, 0.38]
Somatic Anxiety	0.46	0.65	0.12	[-0.32, 0.48]
Self-Confidence	0.58	0.57	0.14	[-0.26, 0.40]
Coping with Adversity	2.05	0.11	0.66	[-0.01, 0.91]
Coachability	0.29	0.77	0.08	[-0.34, 0.45]
Concentration	0.49	0.63	0.10	[-0.30, 0.39]
Confidence and Achievement Motivation	0.15	0.88	0.07	[-0.36, 0.42]
Goal Setting and Mental Preparation	0.25	0.81	0.09	[-0.33, 0.37]
Peaking under Pressure	0.53	0.60	0.11	[-0.31, 0.41]
Freedom from Worry	0.18	0.86	0.06	[-0.35, 0.43]
Two-hand Coordination	0.41	0.68	0.13	[-0.32, 0.46]
Signal Detection	0.30	0.77	0.08	[-0.34, 0.38]
Time-movement Anticipation	0.59	0.56	0.10	[-0.29, 0.39]
Reaction Time	0.47	0.64	0.12	[-0.28, 0.41]
Emotional Stability	0.21	0.83	0.09	[-0.33, 0.40]
Extraversion	0.38	0.70	0.11	[-0.30, 0.38]
Openness	0.51	0.62	0.14	[-0.28, 0.39]
Conscientiousness	0.34	0.74	0.08	[-0.35, 0.43]
Agreeableness	0.29	0.78	0.07	[-0.33, 0.37]

4.5 DISCUSSION

This chapter focuses on objective 4 by extending the scope of the investigation in Chapter 3 from physical parameters to psychological and psychomotor parameters of clay shooting performance. The findings in this chapter shed light on the coping mechanisms of successful clay shooters and their ability to navigate adversity, confirming the significance of coping skills in achieving success in Olympic clay target shooting. The results are consistent with the observations made by Coleman (1980), highlighting that better-performing shooting athletes possess better coping skills and the capacity to construct adaptive cognitive frameworks to perceive reality. Additionally, this investigation's outcomes align with previous research by Cresswell and Hodge (2004), which identified significant correlations between sports confidence, trait anxiety, and coping skills. Particularly, Coping with Adversity scores were positively associated with confidence scores, supporting the inclusion of personality traits like confidence and anxiety in the coping model proposed by Hardy et al. (1996). Researchers should acknowledge the interplay between confidence, anxiety, and coping processes, as these psychological factors can influence athletes' responses to challenges and stressors. In addition, the findings of Nieuwenhuys and Oudejans (2010) indicated that the shooting accuracy of examined police officers experienced a decrease while under elevated levels of anxiety, and the cause of this decline in performance was due to the participants' increased speed of movement. In addition, participants of this study also increased their frequency of blinking, resulting in more extended periods with their eyes closed. However, the examination using the VTS did not reveal significant correlations between the selected parameters and shooting performance level. While the initial findings may not be conclusive, this study highlights the potential value of further investigating cognitive and psycho-physiological parameters using the VTS or similar contemporary diagnostic tools. The demands of Olympic clay shooting, such as eye-hand coordination, visual sensor-motor processing speed, reaction time, and time-movement anticipation, necessitate in-depth exploration through digitalized psychomotor diagnostics. Researchers can take inspiration from studies conducted in other sports using VTS to assess visual-motor processing and peripheral vision. For instance, Zwierko and Lesiakowski (2014) investigated visuomotor processing after gradually increasing physical exercise, while a study by Zwierko et al. (2010) examined the speed of visual sensorimotor processes in volleyball players. These examples demonstrate the potential for utilizing VTS to explore cognitive and psychomotor aspects of athletic performance. Of particular interest for future exploration in clay shooting is peripheral vision, which plays a crucial role in the Skeet discipline, where shooters must aim and shoot simultaneously at two discs flying from opposing directions. A study by Poliszczuk and Mosakowska (2009) examined peripheral perception and time-movement anticipation in elite Badminton players using VTS, and a study by Mańkowska et al. (2015) explored time-movement anticipation and reaction time in female basketball players through visual perception. Such investigations have the potential for transferability to clay shooting and warrant further exploration. Further research in this area is essential, given the novelty of computer-based testing in Olympic clay shooting. Combining subjective self-report assessments and computer-based testing allows for a more comprehensive psychomotor analysis of competitive clay target shooting athletes and it will increase our understanding of the psychological and psychomotor demands for better performance in theses disciplines.

CHAPTER 5: The Importance of Bilateral Limb Symmetries in Olympic Clay Shooting: A Prospective Intervention Study

5.1 INTRODUCTION

The pursuit of excellence in competitive shooting has been studied by researchers for a long time, investigating the best physical conditioning for optimal performance. In 1998, Hawley and Burke concluded that physical training plays a vital role in preparing competitive shooters for the demands of their sport. Recently, Sobani et al. (2022) suggested that shooters' training programs should include physical and mental training to improve their performance, which confirms the conclusions of Mon-López et al. (2019). They highlighted the challenge of competitive pressure on the physical fitness of shooters and suggested that better physical fitness can lead to better performance. However, as discussed in Chapter 2, there is still a gap in empirical research and recommendations regarding the specific physical attributes that Olympic skeet shooting athletes should possess. To address this, Chapter 3 investigated which fitness parameters correlate strongly with clay shooting performance. Interestingly, none of the tested fitness components, such as VO_2 max, strength, flexibility, and reaction time, were revealed as significant predictors of performance. Nonetheless, Chapter 3 noted a vital finding related to performance. It was argued that athletes with better bilateral symmetry in shoulder mobility and grip strength were also the best-performing shooters. Additionally, the potential importance of minimizing asymmetries by implementing personalized drills in the training routines was suggested. This is based on extensive evidence from other sports that symmetrical corrections can reduce injuries and improve performance (Daneshjoo et al., 2013; Maloney, 2018).

It is important to remember that clay target shooting is classified as a bilaterally asymmetric motor task, just like the golfer's swing (Guiard, 1987). In both sports, dynamic movements are driven by the non-dominant hand around a vertical axis. It was suggested by Kalata et al. (2020) that such repetitive asymmetric movement and body positioning could result in unilateral limb dominance, leading to muscle tissue shortening and reduced joint mobility. While Chapter 3 explores the presence of upper body asymmetry, there is a lack of research that focuses specifically on lower body asymmetry in shooting sports. The negative impact of lower body asymmetry on performance has been recognized in other sports, such as track and field and swimming, as pointed out by Bishop et al. (2017). Additionally, the same authors suggest that reducing leg asymmetry to 10% or less can enhance athletic abilities. However, there is a dearth of such investigations in shooting sports, where fine motor control is vital (Raisbeck & Diekfuss, 2015). Empirical work concerning the potential effect of lower body asymmetry on clay shooting performance remains scarce (see Chapters 2 & 3). In response to this scientific disparity, the present study attempts to provide further insights into the significance of neuromuscular symmetries of the upper and lower body for performance optimization in Olympic clay shooting.

The investigation presented in this chapter explored the relationship between an intervention study focused on asymmetry correction and shooting accuracy using individualized training programs focused on the two most prestigious clay shooting disciplines, Skeet and Trap. Achieving excellence in these unique shooting disciplines requires a comprehensive understanding of the impact of neuromuscular asymmetry on performance. This study is, therefore, an important step towards addressing the most critical physical fitness factors that influence shooting accuracy in Olympic clay shooting.

5.2 MATERIALS AND METHODS

5.2.1 Participants

The sample size for the 6-week intervention study was determined using power analysis and G*Power software (Faul et al., 2007). With a medium effect size, a significance level of $\alpha = 0.05$, and a required power of 80%, the calculated sample size was 42. Initially, 44 members of the Cyprus Shooting Federation were recruited for this study, but due to the ongoing pandemic, only 33 athletes could eventually participate. The participants consisted of 8 females and 25 males with an average age of 29+/-7 years. Of these, 11 participants competed in the Skeet and 22 participants competed in the Trap discipline. Performance levels were categorized into two groups: club level (n = 20) and national level (n = 13). Club-level participants achieved an average training score per shooting round of 19/25, while national-level participants achieved an average training score of 22.5/25. Before taking part in the examination, every participant was required to thoroughly read an information sheet and provide informed consent by signing it. The study was approved by the university's ethics committee (BAHSS518 Study4) per the Declaration of Helsinki's ethical principles for research involving human participants. Eighteen participants (5 females and 13 males, Mage = 29+/-7 years) were assigned to the intervention group, while 15 participants (3 females and 12 males, Mage = 29+/-6 years) were assigned to the control group. The intervention group had eight national level and ten club level shooters, while the control group had five national level and ten club level shooters. The selection of participants for the intervention and control groups was based on practical considerations, including the athletes' commitment to the study and their willingness to engage consistently in the training program. Athletes in the intervention group were chosen for their previous involvement in structured training and their demonstrated ability to follow a training regimen reliably. These athletes were also expected to provide honest and constructive feedback, which would help evaluate the effectiveness of the intervention. The control group, by contrast, consisted of athletes who were not involved in the intervention but were matched for similar baseline characteristics, such as skill level and prior experience, to minimize bias and ensure a fair comparison.

It was decided to continue the study for six more weeks to see how the program's effects hold up over a longer period. For the additional 6-week follow-up study, only 17 of the initial 33 participants were able to continue. The main reason for this reduction was the participants' intense training and competition schedules that resumed after the pandemic. These commitments made it difficult for many of the initial participants to find the time and energy to stay involved in the study. As a result, only those who could balance their demanding schedules with the study requirements remained for the follow-up period. In the remaining intervention group, five were national level shooters and six competed at club level (five females and six males; average age = 29 ± 3 years). From the control group, two national level and four club level male shooters continued (average age = 35 ± 6 years).

5.2.2 Experimental Procedures

During the study, only shooting scores from training sessions were recorded to avoid the potential negative influence of psychological pressure that may arise during official competitions. The average shooting score per round of 25 shots from the participants' previous two weeks of training was calculated and recorded. Following the baseline assessment, participants in the intervention group received individually tailored exercise programs designed to target and improve the detected neuromuscular asymmetries. This personalized approach aimed to minimize the identified imbalances and potentially improve shooting performance. Equally, the control group was told that the tests were part of their usual fitness assessment and instructed to continue their regular exercise routine. After six weeks, all participants were retested using the same methodologies as during the baseline assessment. The shooting scores were registered and analysed over the two weeks following the six-week period, specifically in week 7 and 8. This follow-up assessment allowed for a comprehensive comparison of their progress and the impact of the intervention. Moreover, the study continued for an additional six weeks, with 17 of the 33 athletes initially involved (see Figure 12). These remaining participants resumed the study at week 9, following the two-week shooting score collection and analysis period. At week 15, they were tested again, and their shooting performance registered during the subsequent two weeks.

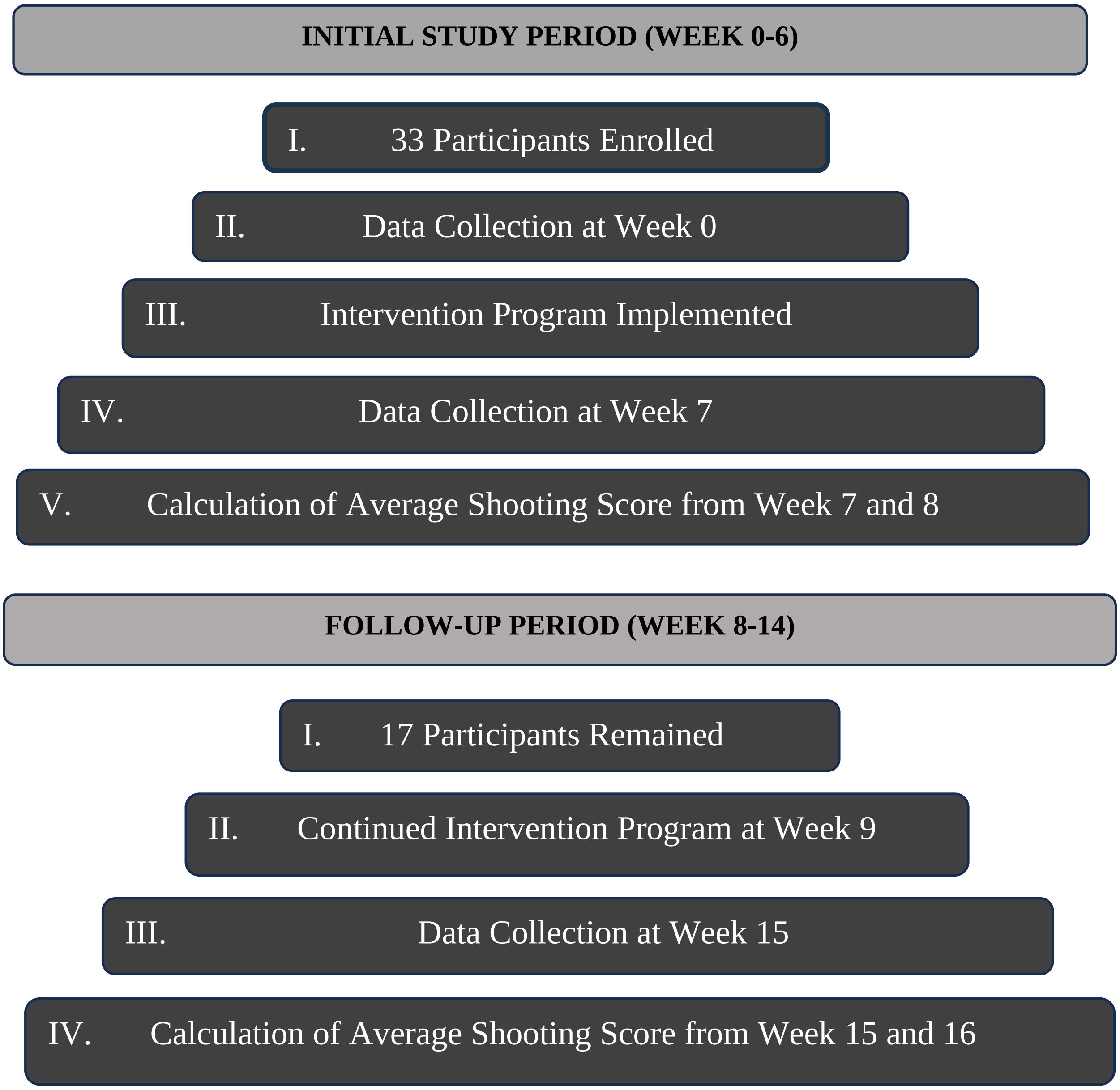


Figure 12: Schematic Experimental Design

5.2.3 Testing Procedure

At first all participants underwent testing across various parameters in a one-hour session, including gender, age, discipline (Skeet or Trap), and average shooting score of the previous two weeks of training. Appropriate warm-up routines were performed before each test to ensure proper preparation and minimize the risk of injury. The study was designed to evaluate specific fitness parameters to understand an athlete's performance potential and injury risk, including four tests to assess bilateral shoulder mobility, static single-leg balance, grip strength and lower body mobility. In this comprehensive analysis, these tests were selected as key tools: (1) Apley's Scratch Test, (2) Unipedal Stance Test with Eyes Open and Closed, (3) Handgrip Dynamometry, and (4) Lower Quarter Y-Balance Test. The tests were performed to compare the two sides and determine the degree of asymmetry for each parameter.

5.2.3.1 Apley's Scratch test

The Apley's Scratch Test is a widely used method for assessing the range of motion in the shoulder joint. Participants stand before a wall and are asked to touch it with their toes without bending forward. Participants extend their arms horizontally from the shoulders while forming fists with their hands. The test involves a reciprocal reaching pattern, whereby participants execute external rotation of one shoulder and internal rotation of the other arm. In this position, the distance between the two closest bony prominences of the fists is measured in centimetres. The procedure is repeated three times on each side, with one-minute rest between attempts, and the best result is recorded. Dewhurst and Bampouras (2014) reported a reliability coefficient of r = 0.80.

5.2.3.2 Unipedal stance test with eyes open and closed

The Unipedal Stance Test with Eyes Open and Closed assesses single-leg balance and static postural control. Participants stand on one leg with the other foot above the ankle of the stance leg, with their hands on the hips. Participants focus on a point before them for the first 30 seconds of the test. After the first 30 seconds, they close their eyes for the remaining 30 seconds. The assessment records the time participants maintain balance on one foot. The test is performed three times on each foot, with a 3-minute rest period, and the participant's best time is recorded. The test termination occurs when the maximum duration of 60 seconds is surpassed, any movements are made with the weight-bearing foot to sustain balance, the resting foot of the weight-bearing leg is moved, arm(s) are detached from the hips, or eyes are opened during the second 30 seconds of the test. This test's interrater reliability correlation coefficient is r = 0.99 (Springer et al., 2007).

5.2.3.3 Handgrip strength

Handgrip Strength is assessed using a handgrip dynamometer (Grip D, T.K.K. 5401, Takei Scientific Instruments, CO., Ltd. Japan), indicating an excellent level of reliability (r = 0.90, Adams, 1998). Participants grip the dynamometer in a position tailored to their hand anatomy comfortably and securely between the palm, the thumb's base, and the fingers' second phalange. Participants lean forward and flex their elbows as they squeeze the apparatus for 2–3 seconds with maximum force. The test is performed three times for each hand, with a 3-minute rest interval between each attempt. The highest result for each hand in kilograms (kg) is recorded, reflecting the participants' maximum handgrip strength for analysis and comparison.

5.2.3.4 Lower Quarter Y-Balance test

The Lower Quarter Y-Balance (YBT-LQ) test is used to identify potential bilateral movement limitations and asymmetries within the lower body (Gorman et al., 2012; Shaffer et al., 2013). The YBT-LQ test kit consists of a stance platform with three pieces attached, enabling participants to perform reaches in three directions: anterior, posteromedial, and posterolateral. Participants have a warm-up trial to familiarize themselves with the equipment and activity before conducting the test. The recorded measurements in centimetres from each leg are compared across all three reaching directions to assess bilateral asymmetries. The composition score of each leg is recorded and compared to the other leg. This score is calculated based on the length of the dominant leg (measured from the anterior superior iliac spine to the medial malleolus) and the results from all three reaching directions of the one leg. The interrater test–retest reliability of the YBT-LQ test has been reported as r = 0.85 to 0.93 (Shaffer et al., 2013).

All of these tests serve as tools to assess shoulder mobility, static single-leg postural control, handgrip strength, and lower body movement limitations and asymmetries. This information helped in developing personalized training programs to address these areas and potentially enhance shooting performance. Incorporating these tests into future assessment protocols can further enhance understanding of the athlete's specific physical capabilities.

5.2.4 Intervention Program

The intervention program used in this study was based on a detailed review of scientific literature about the importance of bilateral symmetry in enhancing overall performance. This literature review was presented in the study by Maloney (2018). The intervention program was integrated into the participants' existing training programs, using previous studies in other sports disciplines as a guide. The program started with appropriate warm-up exercises followed by personalized corrective exercises. The approach to designing the intervention program was inspired by the findings of Gonzalo-Skok et al. (2017), who suggested using unilateral training with a specific focus on the 'weaker' side. The intervention training program was tailored to individual needs identified after assessing (1) the bilateral difference in shoulder mobility, (2) the bilateral difference in handgrip strength, (3) the bilateral difference in static single-leg balance, and (4) the bilateral difference in lower body mobility. After the assessments, the participants' shooting coaches were informed accordingly and were responsible for ensuring that the athletes strictly followed the prescribed training plan (see Section 5.2.4.1). As part of the training program, participants incorporated the prescribed intervention program, which included additional flexibility and balance exercises in the warm-up routine before the shooting training. Grip strength training was recommended to be performed on "non-shooting" days or after the clay shooting training to avoid any possible adverse effects of strength training on shooting performance.

5.2.4.1 Assessment report and training plan sample

BILATERAL ASYMMETRY ASSESSMENT REPORT

NAME:__[redacted]__ **D.O.B:**__[redacted]__

DATE:__[redacted]__

AVERAGE SHOOTING SCORE: __[redacted]__ **DISCIPLINE:** __[redacted]__

TEST RESULTS AND RECOMMENDATIONS

Table 4: Asymmetry assessment report

TEST	RESULT	RECOMMENDATION
Shoulder Mobility	The bilateral difference in mobility is: **1cm** (<10%)	The symmetry in shoulder mobility is at a good level and maintenance is recommended.
Grip Strength	The bilateral difference in grip strength is: **1kg** (<5%)	The symmetry in grip strength is at an excellent level and maintenance is recommended.

Single Leg Stability	The bilateral difference in single leg stability is: **14 seconds** (>25%)	The symmetry in single leg stability is at a poor level and **IMPROVENT of is recommended**.
YBT-LQ	The bilateral difference in the: a) Anterior direction: **7cm** (>10%) b) Posteromedial direction: **2cm** (<10%) c) Posterolateral direction: **3cm** (<10%)	a) The symmetry in the anterior direction is poor, and IMPROVENT **is recommended**. b) The symmetry in grip strength is at a good level and maintenance is recommended. c) The symmetry in grip strength is at a good level and maintenance is recommended.

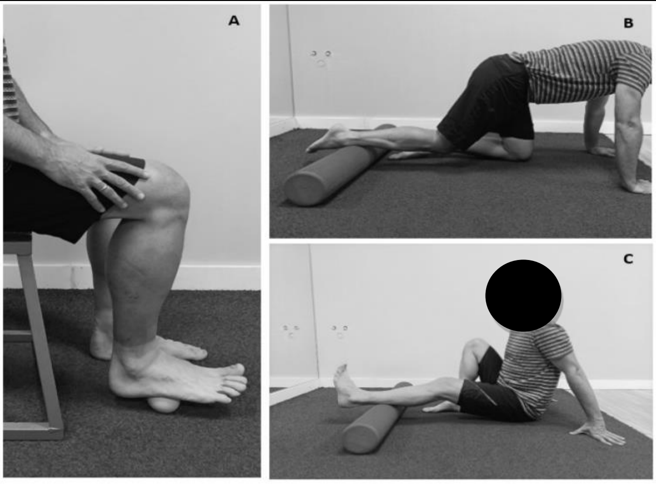
PROGRAM for: [redacted]

Table 5: Corrective training program

General Mobility Drills	Sets/ Reps/ Rest	Frequency
All exercises from the link below: https://www.youtube.com/watch?v=OG1TokL-Its	As recommended in the video	Before the fitness training
Self-myofascial release in the upper back and shoulders		
Massaging the upper back and shoulders with a foam roller and tennis ball. 	5-10 minutes	Daily before the shooting and/or fitness training
Shoulder mobility exercise 1		
SHOULDER CIRCUITS with an elastic band (bring the band from the belly bottom to the lower back, pulling the band slightly out, and reverse – that is one rep)	3 x 10-15reps / 60 seconds rest	Daily before the shooting and/or fitness training (min. 5x per week)

		
Shoulder mobility exercise 2		
BACK WALL STRETCH or DOOR FRAME  	3 x 60 seconds / 60 seconds rest	Daily before the shooting and/or fitness training (min. 5x per week)
Shoulder mobility exercise 3		
STANDING WALL SHOULDER STRETCH Bend your knees slightly and push your chest down, shifting the weight from one side to the other.	3 x 60 seconds / 60 seconds rest	Daily before the shooting and/or fitness training (min. 5x per week)

		
Single leg stability exercise 1		
Stand on the **weak foot** and lift the non-supporting foot off the ground without touching the standing leg. Close your eyes. Try to hold this position for as long as you can	3 x max time	Before the shooting training
Single leg stability exercises 2		
https://www.youtube.com/watch?v=tTQ5QG7rR-s (with focus on the **weak foot**)		Before the shooting training
Self-Myofascial release in the calf and plantar fascia		
https://www.youtube.com/watch?v=sFkTj3g7ja0	5-10 minutes	Before the ankle mobility drill (min. 5x per week)

		
Ankle Mobility Drill		
HALF-KNEELING ANKLE DORSI-FLEXION WITH A DOWEL: (1) Assume a half-kneeling position with a stick placed on the outside of the **restricted foot**. (2) Lean forward and bring the knee to the outside of the stick, ensuring that the front foot's heel remains in contact with the floor and hold the position for 20 seconds. 	2 x 20 seconds / 5 seconds rest	AFTER the shooting and/or BEFORE the fitness training (min. 5x per week)

5.2.4.2 Instructions

An essential part of this study was ensuring that the physical fitness coach correctly demonstrated the prescribed exercises to the participants. Based on the study by Kang et al. (2015), corrective exercises were given to the shooters, considering that attention to detail and clarity in instruction are essential for the success of the intervention program. Demonstrating the prescribed exercises in person allowed the fitness expert to ensure that participants understood the correct form, technique, and execution of each drill. With such an approach, the instructor also receives immediate feedback on the athletes' performance and the opportunity to make corrections and adjustments to prevent incorrect muscle activation or injury. Moreover, individualised instructions allowed the instructor to consider the individual needs and limitations of each participant. Not every athlete had the same range of motion or muscular imbalances, so personalised guidance was essential for tailoring the corrective exercises and addressing specific weaknesses or issues for each participant independently. In addition, detailed programs with explanations, pictures, and links to videos further supported the proper understanding and performance of the exercises. Written explanations helped participants to understand the exercises better. A clear and brief written description was given for all prescribed exercises to prevent mistakes and help athletes stay motivated throughout the training process. Including pictures and links to videos in the materials provided additional visual guidance that supplemented the written instructions (see Section 5.2.4.1). The visual aid made it easier for participants to create a clearer mental picture of the correct body position and movement patterns for each exercise. Links to selected videos were beneficial, as they allowed athletes to see the exercises in action, especially for more complex exercises or movements, ensuring they understood the drills well and could perform them correctly during their training. The training program provided a comprehensive learning experience for the athletes by incorporating demonstrations, written explanations, pictures, and videos. This versatile approach encouraged correct execution and dedication to the prescribed exercise programs.

5.2.4.3 Communication and monitoring

A vital component of the intervention program involved monitoring and maintaining regular communication between participants and the fitness specialist, which allowed to clarify any questions the participants may have encountered while performing the prescribed program. These communications occurred through in-person meetings, phone conversations, or social media, ensuring continuous guidance and support. Furthermore, a logbook was distributed to all participants to track their training sessions and monitor their progress more effectively.

5.2.5 Unilateral training interventions

5.2.5.1 Shoulder mobility

Following the recommendations of Thomas et al. (2018), the participants were instructed to perform shoulder mobility exercises five times per week. As a warm-up, the participants performed dynamic stretching for 3 to 5 minutes, consisting of arm swings/hugs across the body and arm circles using an elastic band. The mobility drill followed and was exclusively focused on the less mobile side: (1) The participants were instructed to stand straight while positioning the back of one hand flat against the lower back. (2) With the “top” hand, they held a rope or elastic band, and the other end with the first hand. (3) They were instructed to gently pull on the rope/band with the “top” arm, allowing the back arm to slide up as comfortably. (4) They were told to hold the stretch for at least 30 seconds, focusing on breathing correctly and maintaining a good posture. Based on Samson et al. (2012), the drill was prescribed to be performed three times with adequate resting periods in between sets. Based on the recommendations of Le Gal et al. (2018)., the participants were advised to perform self-myofascial release for the upper back and shoulders using a foam roller and tennis ball before the stretching drills. Combining self-massage techniques and stretching exercises aimed to relieve muscular tension and improve tissue flexibility, improving the participants' range of motion in the targeted joint.

5.2.5.2 Single leg static postural control

Based on the findings of Marcori et al. (2022), a program of exercises was designed to improve the single-leg stability of the participants. The exercises were prescribed 5 times per week and included in the warm-up routine before shooting or during fitness training. The drills progressed from simple static balance drills to more challenging and dynamic activities, as suggested in previous studies (Muehlbauer et al., 2012; Rasool & Keith, 2007). The gradual progression in the difficulty of exercises allowed athletes to systematically improve their single-leg stability and proprioceptive control. The prescribed dynamic exercises included (1) Forward/backward foot drivers, (2) Lateral foot drivers, (3) Rotational foot drivers, (4) Single leg circles, and (5) Balance to wall touch. The athletes were instructed to perform these exercises 3-5 times in a slow and controlled manner, as suggested by Ruiz and

Richardson (2005). Additionally, the exercises were executed on surfaces of varying stability, such as solid ground, BOSU, balance mats, or pillows, to adapt the participants' neuromuscular systems to the challenging conditions. The approach to progression included additional contra-lateral limb movements, as well as performing these exercises with closed eyes. Furthermore, it was recommended that athletes engage in Tai Chi and Yoga practice, focusing on single-leg stances and movements, as these activities are known to be effective for improving balance (Jeter et al., 2014; Li et al., 2012).

5.2.5.3 Single leg dynamic postural control and mobility

Based on the results of the YBT-LQ test, appropriate corrective exercises were prescribed to address poor execution that was linked to restrictions in the hip and ankle joints. To improve mobility in the posterolateral and posteromedial direction, the program emphasized executing static and dynamic hip mobility drills, starting with a short cardiovascular warm-up (i.e., stationary bike) for 5-8 minutes. Self-myofascial massage techniques were employed to address tissue density and possible trigger points, with foam rolling on the hip and upper leg muscles performed. Tissue lengthening involved static stretching exercises for the hamstrings, quadriceps, hip rotators, and hip flexors, with two sets of 30-60 seconds per stretch. For the central part, dynamic stretching for tissue activation was prescribed using a stepper measuring 20-30cm in height. The participant placed one foot on the stepper and glided the foot of the restricted side in posteromedial or posterolateral directions for two sets of 10 repetitions in each direction (Reiman & Matheson, 2013).

To increase the anterior reach, the focus was on improving ankle dorsiflexion on the restricted side. A massage stick, foam roller, or tennis ball was used for self-myofascial release in the calf and plantar fascia, followed by calf muscle stretching to increase flexibility and prepare the joint for the drill. Half-kneeling ankle dorsiflexion with a dowel was prescribed for two sets of 20 seconds with five seconds of rest in between the sets. Participants were instructed to assume a half-kneeling position with a stick placed on the outside of the foot and lean forward to bring the knee to the outside of the stick, ensuring that the front foot's heel remains in contact with the floor. These mobility exercises were prescribed five times per week, either after the training session or on "days off," to minimize adverse effects on shooting performance, according to Thomas et al. (2018).

5.2.5.4 Hand grip strength

After assessing the grip strength of both hands, the strength training program focused on improving grip strength in the weaker hand. The participants were directed to implement grippers of different resistance levels to address the strength imbalance and support their needs. The resistance drills were recommended 3 to 4 times per week, with a minimum of 48 hours rest for a full muscle recovery. Based on the recommendations of Carpinelli and Otto (1998), the participants were instructed to perform the grip training in 1-3 sets of 5-8 slow repetitions, as low and heavy repetitions engage more muscle fibres and build strength effectively (Westcott et al., 2001). A 3-minute recovery period between sets was prescribed to facilitate recovery further and prevent overtraining. The training progression was carefully planned and detailed in the logbook. The logbook included information about gradually increasing the resistance of the grip training tools, either by using more robust grippers or increasing the resistance on the gripper itself. Involving the "weaker" hand in daily activities was another critical aspect of the training program. Encouraging participants to use their "weaker" hands more in daily tasks such as carrying bags, opening doors, and moving objects helped to reinforce the gains made in the strength training exercises. This functional approach to training ensures that the increased grip strength is transferable to real-life situations and enhances overall dexterity and coordination. Furthermore, using the weaker hand more frequently in daily activities can increase neural activation and motor skill development as the brain becomes more adept at coordinating movements with the non-dominant hand (Carpinelli & Otto, 1998).

Overall, the grip training program focused on improving hand grip strength in the weaker hand through targeted forearm exercises and proper progression. The program's frequency, intensity, and recovery period were carefully considered to promote optimal muscle adaptation. Incorporating the weaker hand into daily activities reinforced the training gains and encouraged the functional transfer of the improved grip strength into real-life situations.

5.3 DATA ANALYSIS

All statistical analyses were conducted using SPSS v25.0 (SPSS Inc., Chicago). Prior to analysis, data were checked for normality using the Shapiro-Wilk test at a significance level of $\alpha = 0.05$. A paired *t*-test was employed to assess within-group changes from pre- to post-intervention in shooting scores and fitness components. The significance level was set at $p < 0.05$. Effect sizes were calculated using Cohen’s d (Cohen, 1988) to interpret the magnitude of change, and 95% confidence intervals were computed for each comparison to provide further context for the results.

5.4. RESULTS

5.4.1 Initial six-week intervention

Following a six-week intervention period, participants were reassessed to evaluate the effectiveness of the program. Following Cohen's (1988) recommendations for using paired *t*-tests to analyze smaller sample sizes, the results indicated that the intervention group demonstrated significant improvements in shooting scores, bilateral hand grip strength asymmetries and the YBT-LQ anterior reach. In addition, the results of the YBT-LQ composition score and the sum in single-leg balance have shown substantial enhancements. Moreover, logbooks of the athletes in the intervention group were analyzed, and it was found that compliance in the intervention group was very high. Specifically, 94% of the athletes followed the given training program consistently, completing the required sessions on schedule, meeting the minimum adherence threshold of 90%. Additionally, 100% of athletes maintained accurate and detailed records in their logbooks, ensuring a high level of commitment to the monitoring process. Furthermore, all participants (100%) of the intervention group attended scheduled check-ins and follow-up meetings, surpassing the required attendance threshold of 80%. These high compliance rates suggest that the intervention was well-received, effectively integrated into the athletes' routines, and that the data collected is reliable, thereby contributing to the potential success of the program.

Table 6: Results of the Six-Week Intervention Study

		Intervention Group *M* ± *SD*	Control Group *M* ± *SD*
Average shooting score (successful shots out of 25)	Pre- intervention	20 ± 4	21 ± 2
	Post-intervention	**21 ± 3****	21 ± 2
Dif. shoulder mobility (cm)	Pre- intervention	4 ± 4	5 ± 4
	Post-intervention	3 ± 3	5 ± 4
Sum for shoulder mobility (cm)	Pre- intervention	39 ± 18	28 ± 15
	Post-intervention	34 ± 17	27 ± 16
Dif. bilateral grip strength (kg)	Pre- intervention	3 ± 2	3 ± 2

	Post-intervention	**2 ± 2***	3 ± 3
Sum for bilateral grip strength (kg)	Pre- intervention	97 ± 28	98 ± 18
	Post-intervention	99 ± 27	99 ± 19
Dif. single leg stability (s)	Pre- intervention	6 ± 6	12 ± 9
	Post-intervention	4 ± 4	9 ± 8
Sum for single leg stability (s)	Pre- intervention	79 ± 31	75 ± 29
	Post-intervention	**100 ± 16***	81 ± 30
Dif. YBT-LQ anterior reach (cm)	Pre- intervention	4 ± 3	3 ± 2
	Post-intervention	**3 ± 2***	3 ± 2
Dif. YBT-LQ posteromedial reach (cm)	Pre- intervention	3 ± 3	3 ± 3
	Post-intervention	2 ± 2	3 ± 2
Dif. YBT-LQ posterolateral reach (cm)	Pre- intervention	4 ± 3	4 ± 3
	Post-intervention	2 ± 2	4 ± 3
Dif. YBT-LQ composition scores (cm)	Pre- intervention	2 ± 2	2 ± 2
	Post-intervention	2 ± 2	2 ± 2
Sum YBT-LQ composition scores (cm)	Pre- intervention	179 ± 11	181 ± 13
	Post-intervention	**185 ± 8****	180 ± 13

Note: * = $p<0.05$; ** = $p<0.01$

Results of the paired *t*-test found significant differences in the intervention group for average shooting score ($t(31) = 4.46$, p<0.001; d=0.78, 95% CI[1.12, 2.36]). Significant differences were also found in bilateral grip strength ($t(31)$ =-2.96, p=0.012, d =-0.52, 95% CI[-1.84, -0.38]), the YBT-LQ anterior reach ($t(31)$=-2.20, p=0.036, d=-0.39, 95% CI[-1.57, -0.04]), the sum for the single leg balance test ($t(31)$=2.32, p=0.027, d=0.42, 95% CI[0.32, 4.28]), and the YBT-LQ composition score $t(31)$=4.17, p<0.001, d=0.75, 95% CI [2.13, 7.24]).

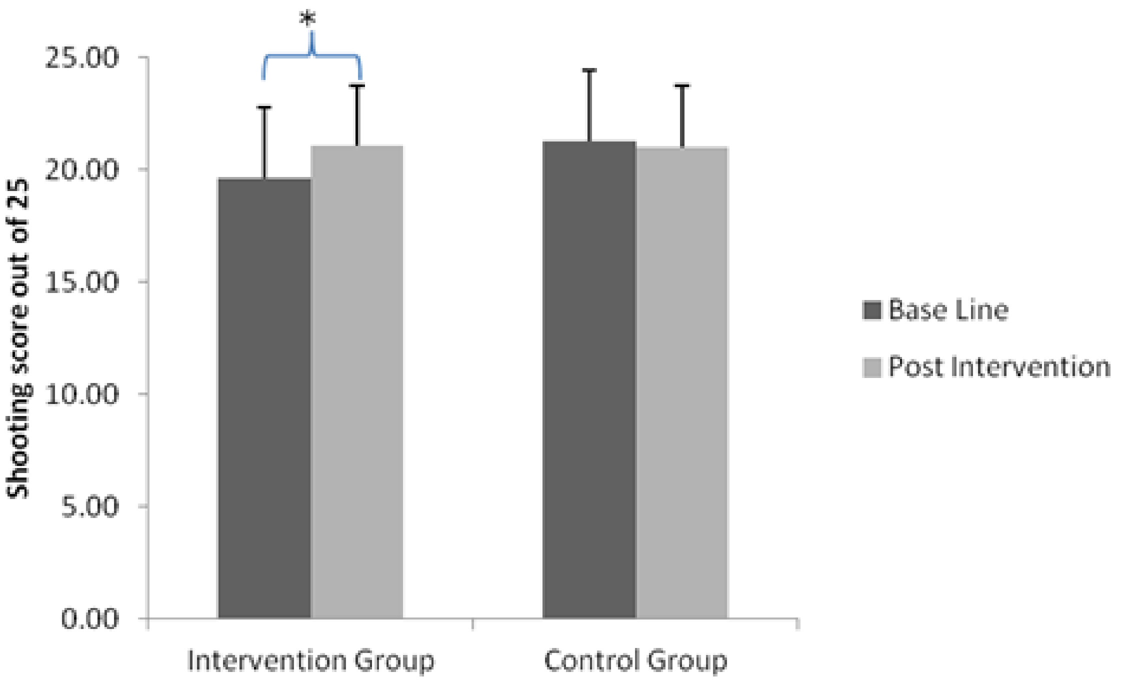


Figure 13: Average training shooting score (per round of 25 shoots) Base Line and Post-Intervention results showing significant differences in the intervention group (*) $p < 0.001$

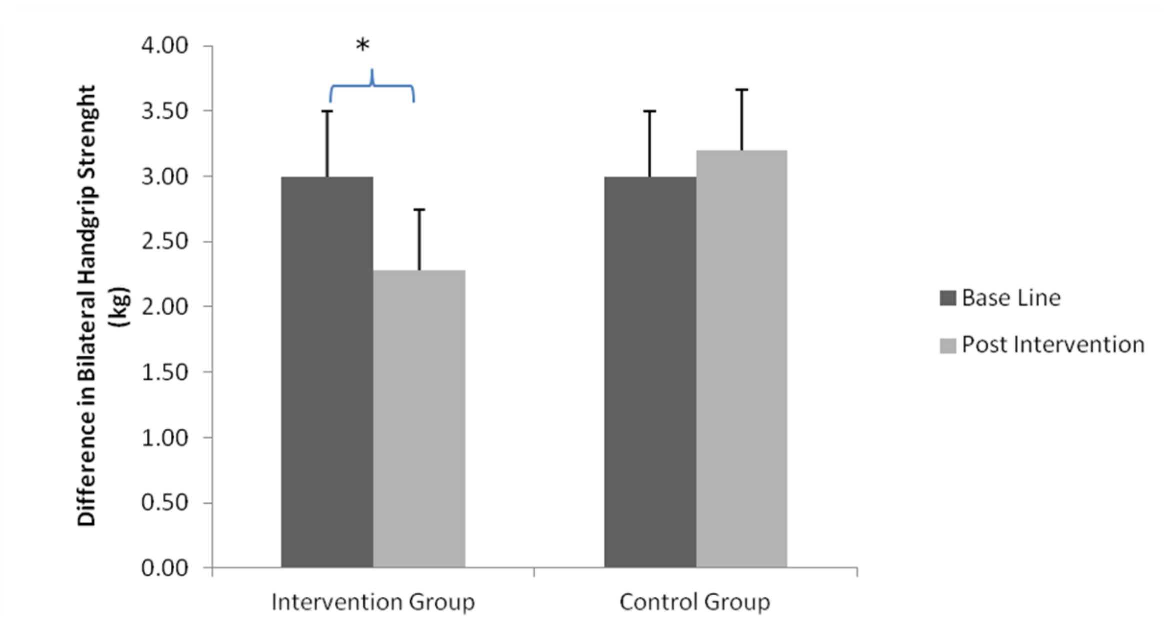


Figure 14: Average difference in bilateral grip strength (kg) Base Line and Post-Intervention results showing significant differences in the intervention group (*) $p = 0.012$

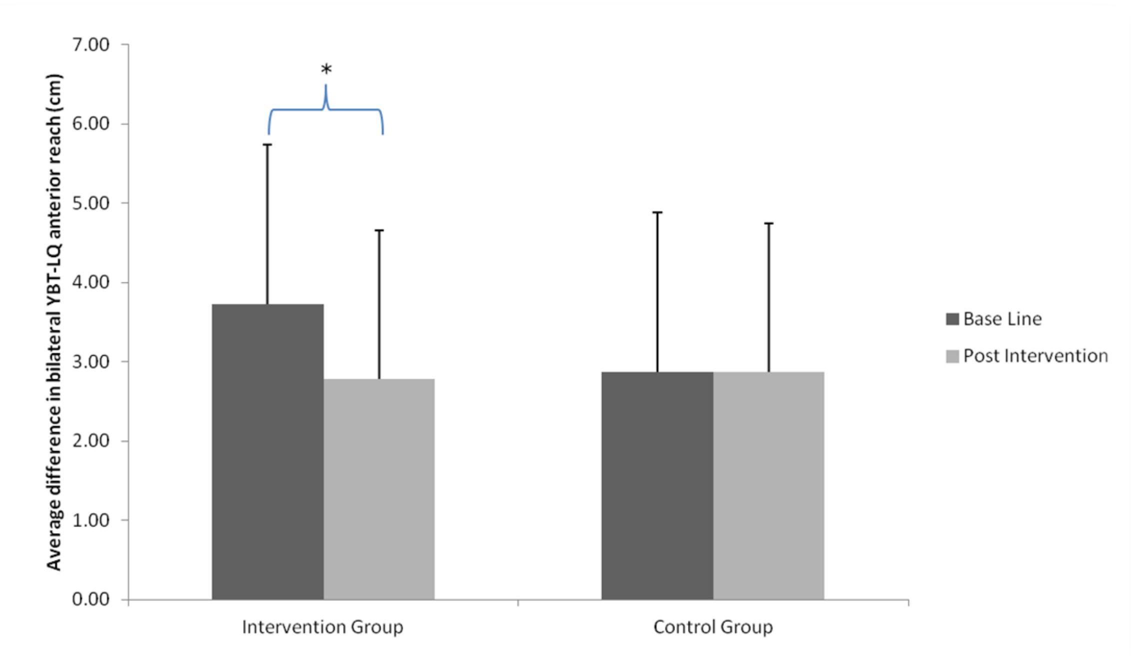


Figure 15: Average difference in bilateral YBT-LQ anterior reach (cm) Base Line and Post-Intervention results showing significant differences in the intervention group (*) *p* = 0.036

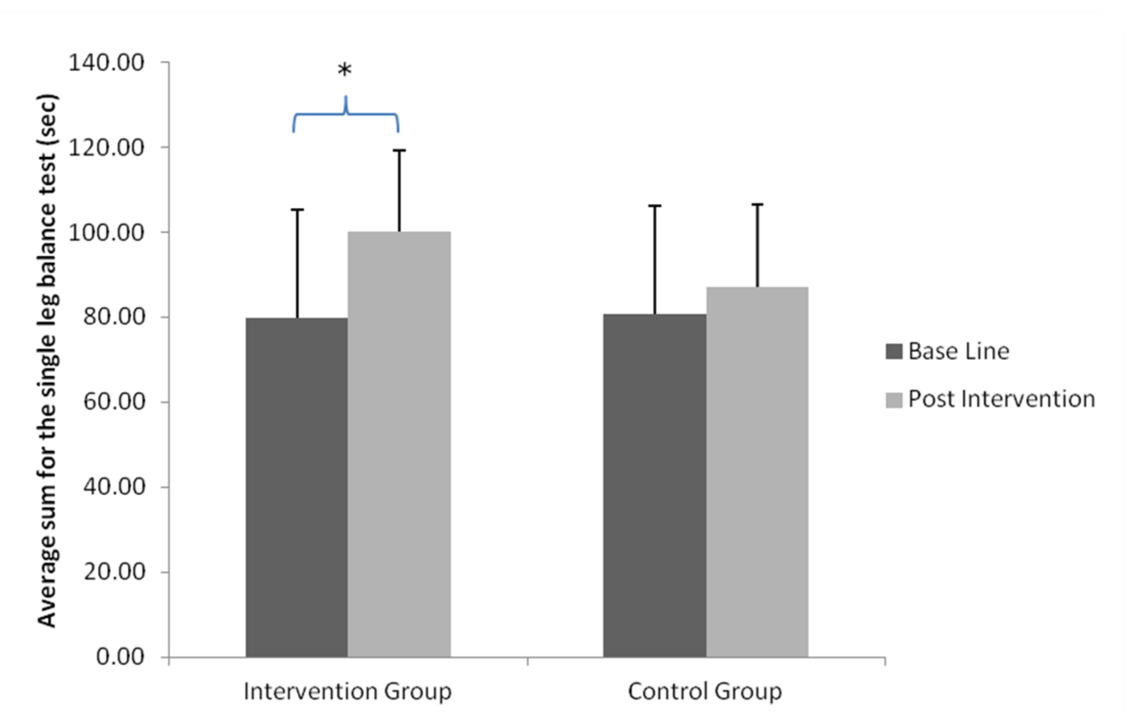


Figure 16: Average sum for the single leg balance test (sec) Base Line and Post-Intervention results showing significant differences in the intervention group (*) *p* = 0.027

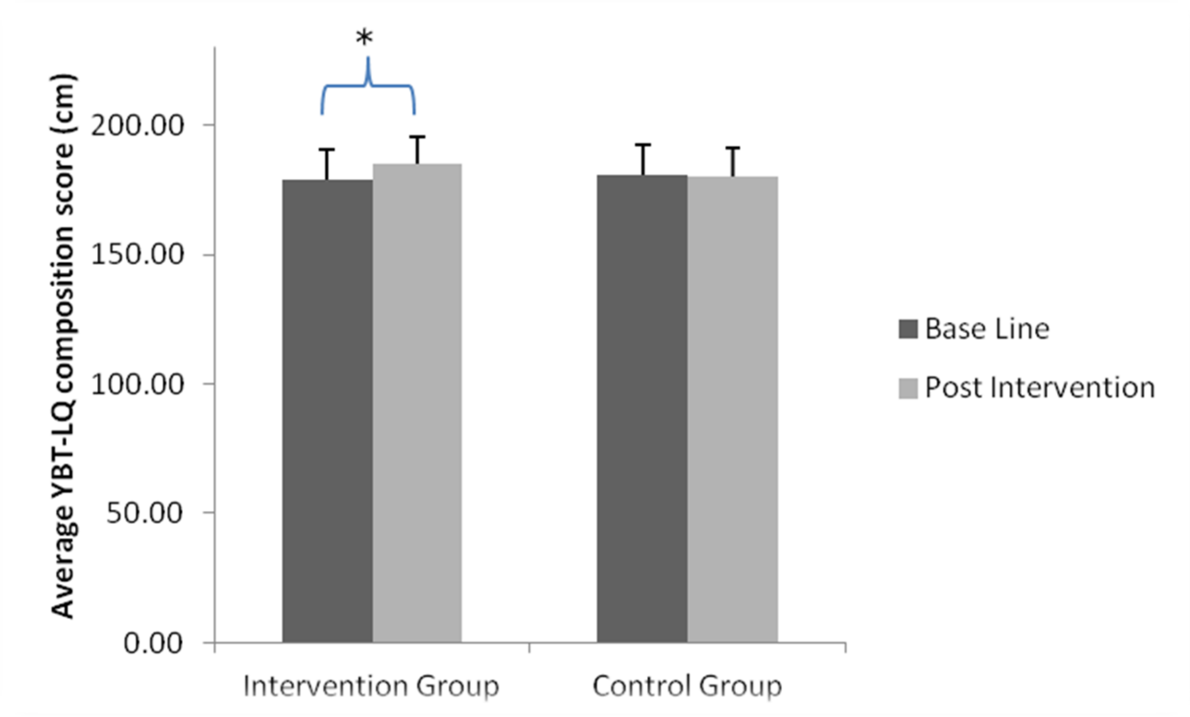


Figure 17: Average YBT-LQ composition score (cm) Base Line and Post-Intervention results showing significant differences in the intervention group (*) $p < 0.001$

5.4.2 Follow up six-week intervention

In the 6-week follow-up study with the remaining 17 participants, a paired *t*-test was used again due to the repeated measures design and the need for greater statistical power. All athletes (100%) consistently maintained accurate and detailed logbook records, showing strong commitment to the monitoring process. However, the analysis did not show any further significant improvements in any of the tested parameters or shooting performance scores for either group.

Table 7: Results of the Follow Up Intervention Study

		Intervention Group *M* ± *SD*	Control Group *M* ± *SD*
Average shooting score (successful shots out of 25)	Pre- intervention	21 ± 3	21 ± 2
	Post-intervention	21 ± 3	20 ± 2
Dif. shoulder mobility (cm)	Pre- intervention	3 ± 3	5 ± 4
	Post-intervention	1 ± 1	8 ± 6

Sum for shoulder mobility (cm)	Pre- intervention	34 ± 17	27 ± 16
	Post-intervention	32 ± 16	30 ± 17
Dif. bilateral grip strength (kg)	Pre- intervention	2 ± 2	3 ± 3
	Post-intervention	2 ± 2	6 ± 4
Sum for bilateral grip strength (kg)	Pre- intervention	99 ± 27	99 ± 19
	Post-intervention	84 ± 23	109 ± 14
Dif. single leg stability (s)	Pre- intervention	4 ± 4	9 ± 8
	Post-intervention	3 ± 2	13 ± 7
Sum for single leg stability (s)	Pre- intervention	100 ± 16	81 ± 30
	Post-intervention	104 ± 11	85 ± 20
Dif. YBT-LQ anterior reach (cm)	Pre- intervention	3 ± 2	3 ± 2
	Post-intervention	2 ± 2	5 ± 2
Dif. YBT-LQ posteromedial reach (cm)	Pre- intervention	2 ± 2	3 ± 2
	Post-intervention	1 ± 1	4 ± 3
Dif. YBT-LQ posterolateral reach (cm)	Pre- intervention	2 ± 2	4 ± 3
	Post-intervention	2 ± 2	5 ± 4
Dif. YBT-LQ composition scores (cm)	Pre- intervention	2 ± 2	2 ± 2
	Post-intervention	1 ± 2	5 ± 3
Sum YBT-LQ composition scores (cm)	Pre- intervention	185 ± 8	180 ± 13
	Post-intervention	184 ± 9	176 ± 18

5.5 DISCUSSION

The study presented in this chapter conducted a pioneering prospective controlled trial to investigate objectives 5 and 6 by evaluating the effects of a program designed to correct asymmetries on Skeet and Trap shooting athletes. The intervention program was based on personalised exercise routines targeting identified asymmetries and close supervision and education of the involved athletes and coaches. The personalised training programs were intended to minimise asymmetries, with the anticipated outcome of improving shooting performance, as suggested in Chapter 3. The review study by Maloney (2018) presented scientific evidence from various sports and illustrated the link between asymmetry and athletic performance. The present study further develops these findings by correcting the discovered asymmetries in clay target shooters and investigating the impact on shooting performance. Key findings of the study include the significant improvement in the mean shooting score among the intervention group members. This improvement in shooting accuracy is seen alongside positive changes in other parameters, such as handgrip strength and lower body mobility symmetry, as well as in single-leg balance. Notably, the study introduces the concept of single-leg balance as a fitness component important for clay shooters, suggesting that good balance on one foot could positively affect shooting performance. The study's results also emphasise the importance of early intervention and suggest that the initial six-week correction program significantly impacted performance. However, the follow-up six-week period did not produce the same improvements. Similar results were reported by Hung et al. (2021) after applying a 6-week functional training program on national team air rifle shooters and significantly improving their stability, fluency, and shooting scores. Furthermore, after a 6-week detraining period, all parameters returned to baseline, confirming strong evidence of positive initial training effects. This implies that maintaining the achieved neuromuscular improvements is crucial for sustained performance benefits.

The study's approach is compared to other sports with similar demands for fine motor skills, such as golf. In both clay shooting and golf, asymmetry is present due to the nature of the movements, and interventions designed to correct these asymmetries have been shown to positively affect performance and injury prevention. Previous examinations in golf used specialised programs designed to improve flexibility and address muscle imbalances caused by repetitive movements, and their effectiveness in both preventing injuries and enhancing performance has been confirmed in golf (Zouzias et al., 2018). Generally, bilateral asymmetry is characterised as a mirrored deviation along the coronal axis, and the motor tasks are as categorised as (1) unilateral, (2) bilateral asymmetric, (3) out-of-phase bilateral symmetric, and (4) in-phase bilateral symmetric (Guiard, 1987). This classification places clay target shooting, golf, and other unilateral sports within the second category. The dynamic body rotation around the vertical axis in clay shooting resembles the rotational movements of a golf swing (Sanders et al., 2011), and both demand high levels of eye-hand coordination and complex sensory-motor skills (DeBrof, 2018). The basic motion in both sports involves dynamic body rotation, led by the non-dominant hand, with similar stress distribution on the myo-skeletal system. However, in clay shooting, the action occurs without further shoulder, elbow or wrist flexion but with an additional impact from the shotgun's recoil.

Almost forty years ago, Leveau and Bernhardt (1984) pointed out that unilateral dominance can occur when asymmetries in mechanical loading are repeated over extended periods and left uncompensated. This imbalance may also shorten the affected muscles, negatively affecting joint mobility (Kalata et al., 2020). Furthermore, Pion et al. (2015) concluded that higher levels of performance lead to greater development of sport-specific physiological and motor characteristics. Furthermore, Vad et al. (2004) showed that, even with correct training, morphological and functional asymmetries can develop due to specific physical stressors. Also, numerous studies highlight the negative impact of muscle strength and morphology asymmetries on performance levels (Grygorowicz et al., 2010; Risberg et al., 2018; Stastny et al., 2018; Vargas et al., 2019). In addition, Afonso et al. (2022) concluded in their review study that some performance asymmetries are inevitable and, in many cases, are not associated with a higher risk of injury in sport. They also argue that asymmetry is imperative from a biological evolutionary perspective and that we should accept asymmetry between limbs as a natural and positive feature of human structure and performance. The authors further conclude that the threshold at which asymmetry becomes dysfunctional depends on the measurement method, task, person, or sport.

This study is the first of its kind in Olympic clay shooting, and the most interesting finding after the six-week intervention period was the significant improvement in average shooting performance in the intervention group. Alongside improved shooting accuracy, this group displayed notable symmetry improvements in handgrip strength, confirming the findings in Chapter 3 that superior clay shooters exhibit reduced bilateral grip asymmetry. In addition, our investigation found significant symmetry improvements in the YBT-LQ for the anterior reach in the intervention group, which may be associated with shooting score improvements. Further, two other parameters that demonstrated significant improvement were the total single-leg balance time and the total composition score in the YBT-LQ. While the difference in single-leg balance correction did not significantly improve, the combined score of both legs notably improved. A recent study by Sobhani et al. (2022) related to these findings, reporting that elite rifle shooters scored higher on the Y-test with the left foot in the back direction. Although previous studies in shooting sports have examined bipedal balance and postural control (Peljha et al., 2021; Puglisi et al., 2014), no previous empirical evidence exists on single-leg balance. The argument could be made that better single-leg balance is a crucial aspect of fitness for clay shooters and that improving this fitness component could benefit shooting accuracy. Furthermore, improvements in overall composition scores on the YBT-LQ may indicate that better lower body mobility is strongly correlated with performance.

To sum up, the initial six-week intervention positively affected shooting scores through enhancements in the previously mentioned parameters. However, further investigation is required to determine which specific parameter or combination of parameters significantly impacts performance. Interestingly, no significant improvements were noted during the subsequent six-week follow-up period involving the remaining 11 participants from the intervention group. These findings suggest that while the initial personalised correction program had a noticeable impact on performance, the effects were not sustained over an extended intervention period. Chapter 3 points out that neuromuscular differences between the left and right sides of the body negatively impact shooting performance and the research presented in this chapter finds additional evidence to support these results. Further, it suggests that reducing these differences impacts shooting accuracy in the Skeet and Trap disciplines. Although these improvements have proven effective initially, their efficacy has been observed to lessen when used for an extended period. The assumption can be made that the initial improvements in neuromuscular symmetry have the greatest impact on performance, highlighting the significance of regularly assessing these parameters.

5.5 CONCLUSION

In conclusion, the findings presented in this chapter explain the complex relationship between shooting performance and various physiological factors, primarily focusing on bilateral asymmetries in handgrip strength and ankle and hip mobility. The study results indicate a significant negative correlation between shooting performance and these asymmetries. This suggests that athletes who possess more significant imbalances in handgrip strength, ankle flexibility, and hip mobility are more likely not to perform to their full potential. Furthermore, this study introduces the novel concept that initial improvements in asymmetry parameters can significantly impact the clay target shooting results. Specifically, minimising bilateral differences in grip strength, ankle mobility, and hip mobility can significantly improve shooting performance in the Skeet and Trap disciplines. Another finding was a strong positive correlation between shooting performance, single-leg stability and overall lower-body mobility. The study presented in this Chapter suggests that clay target shooting athletes with better single-leg stability and higher YBT-LQ composition scores achieve higher shooting results. Given these discoveries, competitive clay shooters are strongly recommended to regularly test upper and lower body asymmetries, single-leg stability, and lower body mobility. These assessments should serve as a foundational component of an athlete's training regimen, guiding the development of personalised training programs to correct identified deficiencies. However, it is crucial to recognise that the study presented was limited by sample size. To strengthen the validity of the results, future studies should include a more significant number of participants. This expansion will increase the statistical outcome of the findings and provide a more comprehensive understanding of the complex interplay between physiological factors and shooting performance. Moreover, future research should investigate further the specific fitness demands and performance optimisation processes unique to Olympic clay shooting. By better understanding the precise physical requirements of this sport, coaches can tailor training protocols more effectively to meet the needs of clay shooting athletes. An interesting thought for future research is to investigate how differences in the bilateral strength and coordination of muscles can affect shooting outcomes. By better understanding how neuromuscular asymmetry affects clay target shooting, experts in the field can develop and further expand specific strategies to improve these imbalances. Overall, the findings of this study highlight the role of handgrip strength, single-leg stability, and lower body mobility in achieving optimal performance. The recommendations in this chapter highlight the importance of regular evaluation and personalised corrective training programs and create a foundation for a better understanding of the complex physical dynamics behind shooting performance in the Skeet and Trap disciplines.

CHAPTER 6: Synthesis of findings

The discussion provided is a comprehensive analysis of the main objectives of this study to establish the most effective physical conditioning routine supporting optimal performance in Skeet and Trap shooting. The first chapter introduces the technical characteristics and differences of the two Olympic clay shooting events. Chapter 2 focuses on objective 1 and reviews the existing scientific literature on the specific physical requirements of the sport by identifying components of physical fitness that have been previously acknowledged through empirical research as potentially relevant to the sport. After uncovering a dearth of published scientific work on the role of physical conditioning in clay target shooting, in Chapter 2, the scientific literature from other shooting sports was investigated as well. That led to the discussion of objective 2 by examining the specific physical requirements of other shooting sports and transferring relevant parameters from other disciplines to Olympic clay shooting. The findings of the desktop study discussed in Chapter 2 were published in the Journal of Human Sport and Exercise, 13(3), and the paper titled 'The relative importance of selected physical fitness parameters in Olympic clay target shooting' was issued in 2018.

Based on the findings presented in Chapter 2, objective 3 was addressed in Chapter 3 by exploring selected fitness parameters that could distinguish skill levels and further investigate the established fitness components with the highest correlation to performance. The study showed that an average level of the tested fitness components was adequate for achieving a high shooting performance, and further increases in these parameters would not improve shooting scores. However, an important finding from a later study was that elite shooters exhibited better bilateral symmetries in shoulder mobility and grip strength. This discovery encouraged further investigation into the potential effects of neuromuscular imbalances, and the results of this investigation were shared with the scientific community through a publication in the Journal of Physical Education and Sport, with the title 'Assessment of physical fitness parameters in Olympic clay target shooters and their relationship with shooting performance,' published in 2021.

Chapter 4 discusses the results of a comprehensive psychomotor profiling of competitive clay shooters. The study, covering Objective 4, examined the complex interaction of various parameters using computer-based tests and self-assessments and found that only the ability to cope with adversity was strongly correlated with performance.

Finally, based on the results of the investigations in Chapters 2, 3 and 4, in Chapter 5, an intervention program was designed and applied to clay shooting athletes to improve their shooting performance. The performance development was monitored, and a foundation for sport-specific training routines covering objectives 5 and 6 was established. The results of study 4 represents and novel finding and make a unique contribution to the clay shooting sport. The findings offer new approaches and ideas that had not been previously considered. This pioneering work increases the understanding of performance measures within the sport and provides a foundation for developing training protocols that can significantly improve clay shooting performance.

Chapter 1 introduces the basics of competitive clay shooting and explains this sport's high technical, physical and mental demands. It is worth noting that many athletes worldwide enjoy this sport, which is also a popular event at the Summer Olympic Games. The two Olympic disciplines of Skeet and Trap and their subcategories are described in detail. Further, the difference between stationery and clay target shooting is explained, with the main difference being the speed and direction of the moving target, which requires the shooter to adjust his aim and timing accordingly. Additionally, the specific equipment used in Olympic clay target shooting is discussed. Clay shooters use shotguns, typically heavier than weapons used in other shooting disciplines, and use specialised ammunition that requires different techniques than shooting with standard ammunition. It is pointed out that besides the physical demands, clay target shooting requires a high mental focus and concentration. Shooters must be able to block out distractions and focus on the moving target to hit it successfully. This requires a great deal of mental discipline and training.

Overall, Chapter 1 introduces the intricate characteristics of skeet and trap shooting and the requirements for the interplay of physical, technical, and psychological aspects. It was concluded that Olympic clay shooting is a complex sport requiring specific physical fitness, continuous technical practice, mental resilience and adaptability to challenging conditions.

In Chapter 2, a literature review is presented, and the desktop study revealed a need for more scientific work in this domain, with only a limited number of relevant studies aligning with the research objectives. While some studies explored unrelated topics, such as environmental effects near shooting ranges, the investigation highlighted the need for further research in this field. Further, the pertinent transfer of empirical studies in other shooting disciplines (i.e., archery, pistol, and rifle shooting) was examined, and four primary areas of focus were identified: (1) postural stability, (2) strength, (3) quiet eye duration, and (4) maximal oxygen consumption. These areas were explored in detail, referencing relevant studies and their findings. The examination highlighted the complexity and, in some instances, the inconsistencies within the literature. Moreover, the initial investigation results emphasised the gaps in the current knowledge and recommendations based on scientific research on the importance of physical conditioning for better performance in Olympic clay target shooting. The literature review underscored the importance of further research in this field and called for a deeper exploration of specific fitness components such as postural stability, strength, flexibility, reaction time, and anthropometric measurements. Finally, it highlighted the potential for enhancing the performance of clay target shooting athletes through evidence-based training regimes based on a better understanding of the relevant fitness parameters.

The paper resulting from this investigation has accumulated over 1,830 reads and has been cited 16 times as of June 2024. It presents significant importance and interesting potential in exploring an under-researched area within its field. The high readership and citations indicate the significance and impact of its findings on the academic and professional community involved in competitive shooting sports. The published literature review addresses a critical gap in the existing empirical work, providing new insights into a previously underexplored area. This contribution is essential for understanding the subject matter and guiding future research directions. By filling crucial knowledge gaps the study has made a significant contribution to its field and the findings of the paper have practical applications as it offers valuable recommendations that athletes and coaches can implement to improve outcomes in the relevant field.

Building on this foundation, Chapter 2 provides an overview of previous studies in other shooting sports, illustrating a correlation between certain fitness parameters and shooting success. However, with the exception of a study by Puglisi et al. (2014), there is a noticeable gap in similar recommendations within the Olympic clay target shooting field. As a result, in Chapter 3 the next examination is described, focusing on identifying the demands in physical conditioning for the Olympic clay shooting disciplines. It was pointed out that more than four decades ago, Corbin and Noble (1980) suggested that possessing specific fitness components enhances performance in physical activities and sports. This principle extends to competitive clay target shooting, a sport demanding distinct physical qualities and imposing unique psycho-somatic pressures on athletes. The question remains whether clay shooters develop these qualities through engagement in the chosen sport or if they are drawn to the activity due to their pre-existing characteristics. As a result, Chapter 3 reports on the exploratory study of distinguishing performance factors among tested parameters, specifically focusing on the strongest associations between examined fitness components and clay shooting success. The study aimed to clarify (1) the link between selected fitness parameters previously examined in other shooting disciplines and present shooting scores and (2) the ability of those parameters to differentiate skill levels within the sport. While previous research in other shooting sports had suggested links between certain parameters and shooting success, this examination identified a slightly different demand in physical conditioning. Opposing the expected result, direct correlations between the examined parameters and performance levels in Skeet and Trap did not appear as significant as anticipated.

This discovery underscores the complexity of the links between physical conditioning and clay shooting performance, encouraging a comprehensive inquiry into the intricate factors involved. After further investigations on the tested parameters, two most relevant discoveries emerged: (1) a strong association between bilateral shoulder mobility asymmetry and (2) handgrip strength asymmetry, with higher shooting scores. This discovery presents a novelty within the shooting sport, as these parameters had not been previously explored in this context. The significance of this finding lies not simply in absolute values but in the symmetry between the bilateral components. This bilateral symmetry was found to be crucial as it highlights the importance of balanced physical attributes in achieving optimal performance in clay target shooting. In other words, the study suggests that success in clay shooting depends not just on improving specific fitness components but that it is even more important that these components are developed equally on both sides of the body. This bilateral balance may contribute to better stability, control, and accuracy, which are essential for high-level performance in shooting sports. Therefore, this insight introduces new approaches for designing training and conditioning programs that emphasize enhancing bilateral symmetry, potentially improving clay shooting performance.

Additionally, regarding skill level, differences emerged in factors like height, mass, flexibility of the posterior muscle chain, and static and dynamic balance, presenting elite performers as lighter, shorter, and possessing superior flexibility and balance. The inclusion of mobility assessment for clay shooting athletes is a novelty but noteworthy considering the specific stance and required dynamic movements in these disciplines. In the single study at hand, investigating flexibility in correlation to shooting performance by Kayihan et al. (2013), the authors suggest strong associations of better posterior muscle chain flexibility with pistol shooting performance. However, the study presented in this chapter could not confirm these findings concerning the examined clay shooters. Recognising the technical disparities between pistol and shotgun shooting, consisting of two-handed aiming and following a fast-moving target before firing, the present study shifted to the upper body, specifically shoulder mobility. Given the persistent strain to the shoulder girdle from holding the shotgun with unsupported arms and forceful recoils, a comprehensive examination of shoulder mobility was justified. Contrary to expectations, restricted shoulder mobility did not adversely affect performance; instead, elite performers possessed significantly greater symmetries in mobility, demonstrating a positive correlation between neuromuscular shoulder girdle balances and shooting accuracy. This novel insight is noteworthy and induces further inquiry into the relevance of bilateral differences in Olympic clay shooting.

Another intriguing parameter that emerged as a performance factor was symmetry in grip strength, with bilateral differences outweighing absolute values, as in the case of shoulder mobility. While previous studies in pistol shooting (Kayihan et al., 2013; Mon et al., 2015; Pellegrini & Schena, 2005; Tang et al., 2008; Vercruyssen et al., 1988) have underscored the importance of grip strength, this study clarifies the distinct technique and biomechanics of competitive clay shooting. The dynamic nature of shotgun shooting introduces different physical demands, specifically on the upper body, including grip strength, compared to static shooting. On that subject, the study of Mon et al. (2019) highlighted the significance of upper body and core strength for shooting athletes without considering the impact of bilateral symmetries for precise performance mechanisms. The negative impact of asymmetries on synchronised whole-body movements was described by Carson and Collins (2016), and it underscores the interdisciplinary importance of symmetry assessment. Extensive evidence from various sports indicates that addressing asymmetry can reduce the risk of injury and improve overall performance. It is further recommended to incorporate specific exercises into the training routines for the reduction of the detected bilateral differences (Bishop et al., 2017; Daneshjoo et al., 2013; Kalata et al., 2020; Knapik et al., 1991; Maloney, 2018). In addition, recent research has revealed a significant link between grip strength asymmetry, lower cognitive functioning (McGrath et al., 2020), and increased inclination to neurodegenerative disorders (Chen et al., 2022). These findings reinforce the impact of grip strength asymmetry on neurological functions, particularly in a complex neuromuscular sport like clay target shooting.

In summary, the two most significant discoveries from this study were the strong association between bilateral shoulder mobility asymmetry and higher shooting scores, and a similar correlation between handgrip strength asymmetry and shooting success. These novel findings reveal that athletes with more balanced shoulder mobility and handgrip strength tend to perform better in the Skeet and Trap shooting disciplines, an area previously unexplored. The significance of these results has garnered considerable attention within the academic community, as evidenced by the publication's readership of over 570 and its three citations as of June 2024. This high level of engagement underscores the study's innovative contribution and the growing interest in the role of physical symmetry in athletic performance.

While Chapter 3 focused on the importance of selected physical fitness components in clay shooting, a vital aspect that requires further exploration in this field is the role of psychomotor and psychological parameters. Chapter 4 explored the complex interplay between these parameters and success in Olympic clay shooting. In Olympic clay target shooting, a unique challenge arises from the intense competition, where minor differences can distinguish between not qualifying for a final and winning a medal. It is not uncommon for competitors in the Olympic clay shooting disciplines to achieve identical scores, leading to tiebreakers and shoot-offs that add to the psychological demands on athletes. Even the slightest pressure can adversely affect performance, underscoring the significance of the psycho-somatic aspect (Coleman, 1980). To some extent, it is essential to highlight further the distinct mental demands of the Trap and Skeet shooting disciplines. In the Trap discipline, shooters must make rapid decisions and adapt strategies to hit moving targets that can move in various directions. In contrast, competitors in the Skeet discipline shoot at two diagonally launched targets but within known trajectories and somewhat slower travelling discs. Therefore, the mental challenges slightly vary between these two disciplines (Coleman, 1980). Previous research by Prapavessis and Grove (1991) emphasised the need for tailored assessments and interventions to enhance clay shooters' performance. They also stressed maintaining an optimal performance mood state during competitions. However, much of the existing research has relied on subjective self-reporting methods (Ong, 2015), encouraging the exploration of alternative, more comprehensive assessment approaches. This study aimed to overcome the limitations of traditional testing methods by incorporating validated computerised tests alongside self-reporting assessments. As Ong (2015) suggested, technology-based assessments allow for more in-depth evaluations of psychological aspects such as stress and motivation. The presented investigation in Chapter 4 combined the modified Competitive State Anxiety Inventory (CSAI-2) and the Athlete Coping Skills Inventory (ACSI-28) with computerised Vienna Test System (VTS) assessments to provide a more accurate psychological profile of clay shooters.

In conclusion, the study investigated the relationship between psychomotor and psychological factors and Olympic clay target shooting performance. A key finding was that successful clay shooters exhibit superior coping mechanisms, underscoring the importance of this parameter. This aligns with Coleman (1980)'s observation that elite shooters possess better coping skills. Although the selected tests from the Vienna Test System (VTS) did not correlate significantly with shooting performance, the study represents a pioneering effort in this field. It suggests the need for further research into cognitive and psycho-physiological parameters using comprehensive tools like VTS, given the distinct psychomotor demands of clay shooting. The study's limitations include its preliminary nature, small sample size, and the novelty of using computerized tests in this context. Future research should focus on more detailed psychomotor profiling with sport-specific participants and integrate self-report assessments and computerized tests. This approach would offer a multidimensional analysis of somatic, psychological, and psychomotor factors, enhancing the understanding of performance optimization in clay target shooting.

Chapter 5 discusses a prospective controlled study that explores the transformative potential of a carefully designed asymmetry correction program for athletes competing in the Skeet and Trap disciplines. Based on a comprehensive approach incorporating personalised exercise routines, the intervention aimed to improve muscular imbalances, resulting in improved shooting performance. After the conclusions in Chapter 3, the intervention program used personalised training drills to improve detected asymmetries and enhance shooting accuracy. The findings presented in Chapters 3 and 5 hold significant new implications for the training and preparation of clay shooters and the broader understanding of asymmetry correction in sports performance. It was observed in Chapter 3 that better-performing clay shooting athletes exhibited smaller asymmetries in shoulder mobility and handgrip strength, underscoring the importance of addressing neuromuscular imbalances in training regimes. This notion aligns with research in various sports (Daneshjoo et al., 2013; Maloney, 2018), which suggests the correction of asymmetries to enhance performance and injury prevention. Furthermore, based on Guiard (1987), clay target shooting is classified as a bilateral asymmetric motor task, underscoring this sport's unique biomechanical demands and making it crucial to account for such asymmetries in training methodologies. A comparative analysis of clay shooting and golf reveals comparable characteristics in the dynamic movement about the vertical axis, led by the non-dominant hand (Cochran & Stobbs, 1968). Further, DeBrof (2018) and Sanders et al. (2011) also highlight these biomechanical similarities between the two sports, establishing a foundation for the interventions employed in this study. This comparison provides further context to the potential consequences of unaddressed asymmetry issues in clay shooting. In addition, Leveau and Bernhardt (1984) exposed the danger of uncompensated asymmetry, leading to unilateral neuro-muscular dominance. These findings were recently confirmed by Kalata et al. (2020), suggesting that neuromuscular asymmetries could lead to the development of unilateral limb dominance and subsequent negative impacts on joint mobility and muscle tissue length. Further, the works of Pion et al. (2015) and Vad et al. (2004) underline the complex interplay between performance levels, specific physiological attributes, and the certainty of asymmetries in most sports activities. Also, numerous other studies highlighted the effects of asymmetries in muscle strength and morphology on performance outcomes (Grygorowicz et al., 2010; Risberg et al., 2018; Stastny et al., 2018; Vargas et al., 2019). In contrast, Afonso et al. (2022) stated that asymmetry in performance is inevitable and does not necessarily correlate with a higher risk of injury in athletes but also concluded that the threshold at which asymmetry becomes dysfunctional depends on the measurement procedure, task, person, or type of sport.

The study presented in Chapter 5 included the exploration of lower body asymmetries, which is a novelty in the domain of shooting sports. Bishop et al. (2017) discussed the harmful effects of lower body asymmetries on performance in track and field and swimming, establishing a potential threshold for asymmetry reduction to enhance athletic prowess. Although this concept has not yet been explored in clay shooting sports, its theoretical implications require further study to fully understand its importance to shooting accuracy. The innovative attempt to improve clay shooting performance demonstrates promising results, as revealed by the distinct improvements in shooting accuracy and symmetrical characteristics. The results presented in Chapter 5 and the notable association with the findings in Chapter 3 on smaller grip strength asymmetry further support the significant role of handgrip symmetry for better clay shooting performance. However, the same outcome could not be confirmed for the shoulder mobility. Nonetheless, the novel exploration of bilateral lower body mobility and single-leg balance correlating to shooting accuracy, absent in prior research, introduces a new dimension to the narrative. Further, it is noteworthy that the initial positive effects from the intervention were significant, and the subsequent decrease in these gains during the follow-up period underscores the distinctive nature of continuous performance enhancement. These findings reflect the assertion made in Chapter 3 that bilateral asymmetry influences shooting accuracy yet underscores the need for further investigation, periodic evaluation and correction of neuromuscular functions and symmetry for a long-term effect. The unique contribution presented in Chapter 5 lies in its application of personalised training protocols targeting detected neuromuscular asymmetries. By focusing on the prestigious Olympic shooting disciplines of Skeet and Trap, the study wanted to lay the foundations for a better understanding of theoretical implications and practical execution of asymmetry corrections. This approach adds significant value to the field by identifying the correlation between symmetry and success and by attempting to validate the effectiveness of corrective interventions in shooting accuracy.

Essentially, Chapter 5 validates the qualities of asymmetry correction in elevating the shooting skill of Olympic clay shooters and underscores the short-lasting effects when sustained over time. This validation is supported by numerous studies from other sports that have examined the impact of biomechanical and neuromuscular adjustments on athletic performance. For instance, research by Lees (2002) highlights that correcting asymmetry can lead to significant improvements in precision and consistency in sports that require high levels of accuracy and control. However, the short-lasting effects of these corrections are an important consideration, which highlights the need for sustained training protocols that integrate asymmetry correction as a continuous process. By combining academic insights with empirical evidence, the importance of correcting asymmetry becomes clear through a systematic approach. This approach initiates a new fitness training and performance optimisation concept for athletes competing in the two Olympic shooting disciplines. By addressing asymmetries, clay shooters can achieve more balanced and efficient movements, which not only enhances their performance but also reduces the risk of injury. This is supported by the work of Myers et al. (2008), who demonstrated that correcting biomechanical imbalances could lead to better performance outcomes and lower injury rates in athletes.

Overall, thesis present a pioneering approach and marks the beginning of a new fitness training and performance optimization concept for athletes in the Olympic shooting disciplines of Skeet and Trap. An initial desktop study revealed a significant gap in the existing literature, with almost no published empirical work in this field, underscoring the novelty and importance of the findings presented. It is concluded that by systematically addressing asymmetries, clay shooters can achieve more balanced and efficient movements, thereby enhancing performance and reducing injury risks. Additionally, the study not only explores the impact of fitness components but also highlights the critical role of psychological and neurological parameters on performance. These findings emphasize the multifaceted nature of athletic excellence in clay shooting, pointing to the importance of a holistic training regimen that incorporates both physical and mental conditioning. Integrating asymmetry correction into training regimens represents an innovative strategy that blends scientific research with practical experience, offering a transformative path for athletes in these precision sports. This approach sets a foundation for deeper exploration within the clay shooting community, encouraging further empirical studies and the development of comprehensive training protocols that could revolutionize how clay shooting athletes train and perform.

CHAPTER 7: Conclusion

The main aim of the thesis was to establish the most significant physical fitness parameters for Olympic clay shooting and to put forward the first science-based recommendations for physical fitness training of competitive clay target shooters. This aim has been met by taking a multi-step approach to examine the complex relationship between physical conditioning, psychological and neuromotor factors, shooting performance, and a summary of practical recommendations. An overview of practical recommendations is provided in Section 7.2.2.

After describing the characteristics of Olympic clay shooting in Chapter 1, Chapters 2 to 5 explain how the research objectives were achieved. The main objectives of each study were carefully outlined in Chapters 2-5, and the findings of each study were analysed in detail to clarify the complex connections between these factors and performance. This study's first and second objectives were investigated by conducting an in-depth desk study, discussed in Chapter 2, highlighting the need for more scientific work in this domain. The initial undertaking of a literature review clarified the need for more scientific exploration in this field, with only a small number of pertinent studies aligning with the study's research objectives and some studies examining unrelated areas. This scarcity underscored a critical need for further research in this domain. Moreover, the study considered the transfer of empirical insights from other shooting disciplines, which indicated areas that require attention. While inconsistencies within the literature were apparent, this study emphasised the need for further research to establish a solid foundation of knowledge regarding the significance of specific fitness components for optimal clay shooting performance. This comprehensive review also revealed the broader scope of inquiry within shooting sports, such as hand tremors, breathing regulation, cardiovascular adaptations, and EEG alpha-power reactivity, underscoring the potential for future exploration. In short, the outcomes of the initial literature exploration confirmed the significance of further studies in this field, revealing the gaps in the existing scientific literature and underscoring the importance of implementing empirical findings into the training and preparation of shooting athletes. This study underscores the enormous potential held within evidence-based training regimes based on understanding the complex interplay between different parameters and performance optimisation in Olympic clay target shooting.

The third objective was to examine Skeet and Trap athletes' specific physical fitness requirements, which were presented in Chapter 3. The results of this study did not meet the initial expectations of identifying performance factors among the parameters examined, as none of the examined fitness components showed significant correlations with shooting performance. However, discovering a strong correlation between bilateral asymmetries in shoulder mobility, grip strength, and shooting accuracy opened up new perspectives in the clay target shooting community. This emphasises the importance of considering bilateral symmetry as a determinant of success in clay shooting, highlighting the complex interplay between neuromuscular balances and clay target shooting skill. Additionally, this study investigated the distinct characteristics of elite performers, including their height, mass, flexibility, and balance. In conclusion, the results in Chapter 3 contributed novel insights into the world of competitive clay shooting, revealing the significance of bilateral symmetry in shoulder mobility and grip strength as critical factors linked to performance.

Objective 4 was investigated in Chapter 4, focusing on a comprehensive examination of competitive clay target shooters' psychological and psychomotor parameters. This study provides diverse analyses using the Vienna Test System (VTS), Modified Competitive State Anxiety Intensity-2, and the Athletes Coping Skills Inventory. The research highlights the importance of coping with adversity and the need for further investigation using advanced diagnostic tools such as VTS. Addressing cognitive and psycho-physiological demands in clay shooting will provide deeper insights into factors contributing to shooting excellence and contribute to improved scores.

Objectives 5 and 6 are examined in Chapter 5, where the focus is on implementing a training program specifically designed to improve the performance parameters identified in Chapter 3 and examining whether further improvements in these parameters lead to better shooting performance. Chapter 5 thoroughly examines the complex relationship between shooting performance and various physiological factors, primarily focusing on bilateral asymmetries in shoulder mobility, handgrip strength, single-leg balance, and ankle and hip mobility. The study reveals a significant correlation between asymmetries and shooting performance, indicating that athletes with more significant imbalances in certain areas may not reach their full potential. Moreover, the concept of initial enhancements in handgrip strength, ankle mobility, and hip mobility positively impacting shooting scores is introduced, suggesting that targeted improvements in these parameters can significantly enhance overall shooting performance. A noteworthy finding highlights the correlation between single-leg stability, general lower-body mobility, and shooting performance. Athletes with better single-leg stability and higher scores on the YBT-LQ composition score tend to achieve higher shooting scores, emphasising the importance of a functional lower body base for accuracy in Olympic clay shooting disciplines.

In conclusion, it is highly recommended that athletes and coaches regularly evaluate competitive clay target shooters for upper and lower-body asymmetry, single-leg stability, and lower-body mobility. These assessments form a fundamental component of an athlete's training program and guide the development of an individualised training program to address identified deficiencies. However, it is essential to acknowledge the limitation of the present study due to the small sample size. Future investigations should include a more extensive and diverse group of subjects to strengthen arguments and conclusions. This expansion will improve the statistical strength of findings and offer a more comprehensive understanding of the complex interplay between specific physiological factors and shooting performance. Understanding the exact physical requirements of this sport will enable researchers and coaches to tailor training protocols more effectively to meet the needs of clay shooting athletes. A prospective direction for future research is to explore how bilateral differences in strength and mobility can affect shooting outcomes in the Skeet and Trap disciplines. The suggested guidelines highlight the need for regular assessment and personalised training regimens while recognising the importance of further investigation for excelling in these shooting disciplines. This study is a foundation for comprehending this sport's complex physical demands.

7.1 CONTRIBUTION TO PRACTICE AND KNOWLEDGE

The potential impact of neuromuscular asymmetry on clay target shooting performance and injury prevention is still unknown but represents a promising area for further research. This understanding led to a prospective controlled intervention study in Chapter 5, introducing an innovative approach addressing neuromuscular asymmetries in Skeet and Trap shooting athletes. This study showed promising results in improving presented shooting accuracy by developing a personalised asymmetry correction program and minimising the detected asymmetries. This intervention confirmed the positive relationship between symmetry and performance in the two Olympic clay shooting events, and the results from the intervention study highlight the importance of regular assessment and correction of bilateral neuromuscular balance for performance optimisation in these sports disciplines.

Detecting and addressing asymmetries and functional limitations in the upper and lower body using the tests presented in Section 5.5.2 provides a valuable tool for identifying potential movement disorders and guiding corrective strategies. Furthermore, such training programs must adopt an individualised approach and demonstrate and explain corrective exercises prescribed by experts. Demonstrations, written explanations, additional visual aids (e.g., images and video links) and ongoing communication provide a supportive and effective learning environment for athletes to complete the prescribed program safely and effectively. In addition to the physical fitness components examined in Chapters 3 and 5, Chapter 4 also examines the complex interplay between selected psychological and psychomotor parameters and shooting success, recognising the unique mental demands of Skeet and Trap shooting. While the VTS did not reveal significant correlations between selected parameters and shooting performance, the study underscored the need to further investigate cognitive and psycho-physiological aspects using contemporary assessment tools. The four studies in Chapters 2 to 5 provide a comprehensive overview of the complex relationships between physical, neurological and psychological factors in Olympic clay shooting performance. The unique findings of this study highlight the need for individualised training programs that target physical and psychological factors to improve shooting accuracy.

Additionally, these findings lay the foundation for future research and promote evidence-based training methods to gain a deeper understanding of the complexities of the clay target shooting sports. The inclusion of asymmetry correction plays an essential role in the physical fitness training for the Olympic clay target shooters, and improving detected asymmetries has proven to be a critical scientifically based approach. Studies in sports performance optimisation demonstrate the connection between neuromuscular symmetry, biomechanical accuracy, injury prevention, and optimal performance. The research conducted by Hrysomallis (2011) supports the idea that shooting accuracy and consistency are directly influenced by a well-balanced neuro-muscular system. Furthermore, Knapik et al. (1991) concluded that an imbalance in muscle strength and flexibility can lead to overuse injuries. Also, Grooms and Onate (2015) addressed the importance of neuromuscular control in injury prevention and noted the need to correct asymmetry to support a precise, controlled, and consistent shooting motion. This is consistent with the conclusion of Wulf and Shea (2004) that the coordination of muscle forces through asymmetry correction promotes the development of muscle memory and expert marksmanship. Furthermore, the mental state and self-confidence of shooters can be negatively impacted by the discomfort caused by neuromuscular asymmetries, highlighting the complex relationship between psychological and physiological factors. This aligns with the findings of Carlson et al. (2018), who emphasise the significance of neuromuscular training in improving athletic performance and increasing mental resilience.

7.2 RECOMMENDATIONS FOR FUTURE RESEARCH AND PRACTICE

Achieving excellence in shooting sports necessitates holistic physical, technical, and psychological development. These interconnected components are essential for success in these unique sports disciplines, as focusing on only one or two aspects would not achieve optimal performance. In addition to the recommendations regarding physical performance factors presented in this study, technical and psychological aspects must be further developed and improved simultaneously.

For technical mastery, shooters must focus on equipment, shooting techniques, and adapting to varying weather conditions. Familiarity with guns, munitions, optics, and other equipment is crucial, as Burris and Hodgdon (2000) emphasized. Consistency in movement and technique is also vital; Ihalinen et al. (2016) found that repetition and consistency in body posture, grip strength, and trigger control significantly impact performance. Additionally, adapting shooting techniques to weather conditions—including wind, light, and temperature—is essential for clay target shooters (Vickers, 1996).

Psychological factors are equally crucial. Haberl and Haberl (2012) explored the importance of maintaining focus in precision sports, while Jones et al. (2007) examined mental resilience. Techniques such as visualization and goal setting, as noted by Munroe-Chandler et al. (2011), can further enhance performance. Optimal recovery and nutrition are also key; Ivy (2004) highlighted the role of nutritional timing in performance, while Drilling et al. (2023) discussed the benefits of sleep monitoring and its effect on motor skills. Developing a personalized sleep hygiene protocol may optimize performance by improving recovery and monitoring fatigue (Costa et al., 2022).

Finally, future research should explore advanced training protocols and technology. For instance, EMG measurements, as demonstrated by Svecova and Vala (2016), could help identify neuromuscular asymmetries affecting shooting accuracy. Video analysis is another tool that can allow shooters and coaches to refine techniques through targeted feedback (Berger & Simons, 2011). Chapter 5 highlights the benefits of correcting asymmetries in training regimens and the importance of maintaining symmetry levels to improve shooting precision. Further studies with larger samples and advanced technologies, such as EMG and acceleration measures (Caccese et al., 2018), are recommended to enhance performance optimization in Olympic clay shooting.

In conclusion, success in Olympic clay shooting depends on a comprehensive approach that incorporates physical, technical, and psychological aspects. These interconnected components contribute to the shooter's ability to achieve consistency in precision. Assessment, training, and development in each area are critical to achieving athletic excellence by exploring new strategies, further research, and implementing modern technologies such as electromyography, video analysis, and computer-based assessment of psychomotor and cognitive skills. Based on the assessment results, experts should further develop and improve athletes in their areas of expertise to optimise overall performance. Given the complexity of the sport, each athlete should follow an individual technical, mental and physical training plan.

7.2.1 The challenges with the translation of research into practice and the benefits of practice-based evidence

The presented thesis results from 15 years of involvement in Olympic clay target shooting as a specialised physical fitness coach. It confirms Gabbett's (2016) suggestion that practical insights from practice-based evidence can help researchers study specific facts and connect theory and practice in that way. Practice-based or practitioner evidence refers to experience gained through practical involvement and professional expertise. When it comes to athletic performance, athletes and coaches gain essential insights through years of training and competing. Polanyi (2009) argued that trainers supplement theoretical knowledge by acquiring practical knowledge through experience. A recent study by Bompa and Buzzichelli (2019) determined that evidence-based practice highly depends on the context, considering the specific requirements of a particular sport. Further, Halson (2014) suggests that coaches frequently customise training plans to accommodate the individual needs of athletes, an aspect that needs to be sufficiently addressed in controlled scientific studies. Furthermore, Joyner and Coyle (2008) conclude that using practice-based evidence allows for quickly adjusting to unexpected challenges and conditions, thereby developing more efficient training strategies. Also, Schmidt and Wrisberg (2008) indicated that coaches can better teach and correct skills by developing refined strategies and techniques through practical experience.

In summary, coaches need to communicate with athletes regularly to get immediate feedback so they can adjust their training, and the interplay between practical experience and scientific research contributes to a better understanding of athletic performance. Based on my subjective experiences and the extensive scientific research discussed in Chapters 2-5, in section 7.2.2, I am providing a comprehensive outline of physical training recommendations for competitive clay target shooters.

7.2.2 Physical fitness training recommendations for Olympic clay target shooters

Physical fitness training for competitive clay shooters should focus on cardiovascular endurance, strength endurance, postural stability, and mobility while addressing specific parameters like bilateral asymmetries of the upper and lower body. Although it is stated in Chapter 3 that a basic level of the main physical fitness components is sufficient, competitive clay target shooters should improve their basic physical conditioning during the offseason and preseason (generally November to January), which provides a good foundation for more sport-specific training during the competitive season.

Competitive clay shooters should improve cardiovascular endurance and shoulder girdle, core, and lower body strength during the off-season. Given the importance of bilateral symmetry outlined in Chapters 3 and 5, athletes should train each limb individually when performing resistance training with dumbbells, kettlebells, resistance bands, and cable machines rather than barbells or machines that use both sides simultaneously. For the reasons stated in Chapter 5, any development or increase in muscle asymmetry should be avoided.

During preseason, athletes should continue building cardiovascular endurance through aerobic exercises (e.g., running, biking, rowing, swimming). In particular, swimming or *water aerobics* are beneficial because they train the cardiovascular system without stressing the musculoskeletal system further, which is strained by repetitive motion and recoil during clay target shooting. Further, stretching exercises should be performed to improve flexibility and mobility, paying attention to the joints involved in the shooting motion (e.g., hips, shoulders, wrists). Exercises combining stretching and strengthening (e.g., Pilates, Yoga) are popular with elite clay shooters and come highly recommended. Balance and postural stability should be developed during this time but must also be maintained throughout the competitive season, as these are critical to maintaining a stable shooting position (see Chapter 2, 3 & 5). Based on the findings in Chapter 5, single-leg drills should be preferred over double-leg balance exercises. For challenging advanced athletes, the single-leg stability exercise can be performed with eyes closed on an unstable/soft surface such as a balance pad. Towards the end of the preseason period, functional and sport-specific strength and endurance should be added to the training routine by incorporating exercises that mimic the movements involved in clay shooting, such as rotational exercises to simulate the twisting motion (e.g. standing/half kneeling/kneeling upper body twists with elastic bands or on the cable machine). During the competitive season, cardiovascular training should be changed from *Continuous* or *Fartlek* to *Interval Training*, mimicking the duration and intensity of competition and simulating the start-stop nature of a shooting competition. An effective way to further develop and maintain specific strength and cardiovascular endurance is to use sport-specific exercises through *Circuit Training* (e.g., single leg/single arm overhead press, upper body rotation, single leg deadlift, single hand press on the fit ball, battle rope drills). In addition, sport-specific exercises such as "dry fire" shooting simulations, reaction time, single-leg balance and eye-hand coordination training (e.g., throwing and catching tennis balls from the wall, *Blaze Pods*) should be practised at the beginning of every training session during the preseason and competitive period (see Table 4).

Table 8: Recommendation for the weekly Physical Fitness Training during Off/Pre/On-Season

Weekly Training during:	***Off- Season***	***Pre- Season***	***On- Season***
Cardiovascular endurance	40%	25%	20%
Strength	40%	15%	5 *
Flexibility	20%	15%	20%*
Strength endurance	-	15%	15%
Balance	-	15%	20%*
Reaction Time & Coordination	-	15%	20%

* = Depending on the outcome of the asymmetry assessment

During the competitive season, coordination and reaction exercises should be performed during the warm-up, while strength and endurance exercises should be performed after the shooting training to eliminate potentially adverse effects on performance. At this stage, it is essential to adjust training volume and intensity and increase technical preparation to achieve optimal performance in the upcoming competition. In addition, athletes should be assessed for asymmetry during the preseason period, as recommended in Chapter 3 and 5, and personalised training recommendations should be provided to the athletes to minimise the detected bilateral differences. An individualised training plan should be incorporated into the shooter's training routine and evaluated repeatedly throughout the competition season. Moreover, monitoring and comparing the shooting results with the assessment results of the three performance components - technical, physical, and mental- is crucial. The feedback from all three areas is necessary to get a clear picture of the strengths and weaknesses of each shooter and understand how to optimise their performance most effectively. Another essential aspect of every athlete's performance is the proper recovery, especially in a sport as complex and physically and mentally demanding as Olympic clay shooting. The foundation of good recovery is quality sleep, adequate nutrition and proper hydration. In addition, massage, hot and cold therapies (e.g., saunas, steam rooms, ice baths), foam rolling and similar forms of self-massage should be incorporated into the daily training routines of competitive clay target shooters. In summary, competitive clay shooting requires a comprehensive approach that includes specific physical training based on the sport's distinctive technical, mental and physical demands and regular evaluation of all three aspects.

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