# The effects of game specific task constraints on the outcome of the water polo shot

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Signed  …………………………………….        Date  ………………………

Katrina van der Wende

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## ABSTRACT

Recent research has highlighted that information-movement couplings are unique to the constraints of the task, environment and performer. This recent research implies that skills should be developed in practice environments that are reflective of those found in competition. Representative environments should also allow the performer to attune to specifying information essential for success of a skill. However, in water polo, shooting practice is often conducted without the presence of a goalkeeper or defender. The aim of this study was to determine the effect of game-specific task constraints on the ball speed, accuracy and technique of the water polo shot.

Ten male competitive level water polo players performed a total of forty shots comprising ten shots in each of four conditions from the 4m-penalty line. Conditions included all combinations of goalkeeper and defender (absent or present). Three Sony mini-digital cameras (50Hz) were placed perpendicular to the movement, giving rear, overhead and a right sagittal view. Ball speed was measured using a Radar-gun (Stalker Pro, USA). For each condition, means and standard deviations were determined for all outcome measures (shooting accuracy and ball speed) and technique variables. A repeated measures ANOVA was used to determine the effect ($p < 0.05$) of the goalkeeper and defender individually as well as in combination on the dependent variables. Cohen's effect sizes were also used to determine the magnitude of the difference between conditions.

The presence of a defender resulted in a significant increase in lateral trunk flexion at ball release, decreased the duration of the shot and selected swing sub-phases (i.e. pick-up to top of back swing time) and significantly altered the placement of the ball in the goal. When the goalkeeper only was present, this resulted in decreases in total shot time and pick-up to top of back swing time and significantly altered the placement of the ball in the goal. The presence of the defender and goalkeeper in combination brought about a moderate effect, decreasing the ball speed, significantly decreasing the success of the shots, scores achieved and significantly altering the placement of shots. Forward

swing distance and selected swing sub-phases (i.e. total shot time, pick-up to top of back swing time, forward swing start to midway and forward swing start to release) were also significantly decreased in the presence of the defender and goalkeeper.

These findings highlight the importance of maintaining appropriate task constraints during water polo shooting practice. In effect the removal of the defender and goalkeeper leads to the development of inappropriate information-movement couplings. Specifically, the presence of the defender and/or goalkeeper lead to reductions in the durations of selected swing sub-phases, resulting in changes in the relative coordination and timing of the water polo shot. These findings indicate that in order to facilitate the development of this specific shooting skill, coaches should structure practice to replicate the perceptual information available during competition.

# CHAPTER 1: INTRODUCTION

## Introduction

Current research examining the development of expertise in sport has identified that the amount of practice an athlete undertakes is a key determinant of ultimate performance level (Ericsson, 2003). However, very few studies have actually examined the most effective ways to structure the practice environment. The practice environment represents all the surroundings that encompass the performance of the skill such as audience or spectators, weather, opponents etc. Most studies on practice have looked at issues such as blocked versus variable practice regimes, the distribution of practice, closed versus open skill or part versus whole skill learning strategies (Magill, 2003).

Coaches understand that in order to achieve high levels of skill, players need to undertake many repetitions of a task before they master it. This leads to a focus on the development of the 'perfect technique'. This ideal is summed up by some coach's favourite quotes 'perfect practice makes perfect' or 'perfect practice makes permanent'. In order to 'perfect' the technique of a skill, certain coaches often develop coaching strategies that incorporate closed skill practice. Closed skills include such tasks as basketball players shooting at an undefended basket, hitting a ball off a tee or shooting in water polo against an empty goal.

The use of closed skill practice is supported by the idea of a reduced attentional load on the player. The human information-processing system has limitations on how many activities can be performed simultaneously (Magill, 2003). An open skill requires a player to attend to the technique of their movement and their surroundings, therefore greater attentional load is placed on the player. By practising closed skills the player is able to focus primarily on the technique of the movement without any pressure from the opposition being present. This reduces the load on the information-processing system and results in a greater degree of initial successful performance of the skill for the player.

However, results from some recent applied research from the field of ecological psychology are beginning to question the value of this drill based approach and

shows that practice environments should be more representative of competition conditions.

Central to the ecological approach is the idea that perception and action are tightly coupled. Perception-action coupling highlights a cyclical relationship of information from the surrounding environment and movements of the performer. The performer continuously uses information to adapt and conduct actions in a real time manner. This continual perception-action coupling was found with one-on-one basketball dribbling, where the goal was to score a basket (Araujo *et al.*, 2004). The continual movement of the attacker and defender provided information on how to achieve their goals relative to the opposition player's movements. The use of the perception-action coupling was also highlighted by the finding that when batting against a bowling machine, the batter's coordination and timing are significantly altered (Renshaw *et al.*, 2004). Skilled batters were unable to use the perceptual information of the real bowler's body actions, which resulted in a breakdown of their information-movement couplings causing disruptions in the regulation of the movement and timing. The importance of learning in practice environments with representative perception information was further emphasised by Renshaw & Davids (2004), who found that cricket bowler's regulated steps throughout the whole of the run-up. This finding demonstrates why practice should be as representative of competition as possible, so that information-movement couplings can be developed to find solutions to the constraints present.

The process of learning motor skills is more explorative in nature than traditionally thought (Araujo *et al.*, 2004). Active exploration of a motor skill will allow a greater amount of success in performance of the skill (Savelsbergh & van der Kamp, 2000). Furthermore, practice of the skill under highly variable conditions allows multiple information-movement couplings to be developed (Savelsbergh & van der Kamp, 2000). Specificity in practice allows players to select and attune to information needed to emerge from specific constraints and develop information-movement couplings (Savelsbergh & van der Kamp, 2000). The more variable and specific practice is, the greater number of information-movement couplings that can be developed for use in a variety of conditions. The development of skills under highly variable but game-specific conditions

will allow players to perform these skills successful in a variety of competitive settings.

To develop functional information-movement couplings, beginners must attune to the specifying information rather than non-specifying information. Specifying information refers to the most important or relevant information within an environment which is needed to perform a skill accurately and most efficiently for that situation. There is some evidence to show that if novice performers use non-specifying variables that resulted in an accurate performance, their long-term skill development could be restricted since they had not become attuned to specifying information which could result in a better performance (Jacobs *et al.*, 2001). This finding would, therefore, suggest that initial practice requires specifying information to be present, so that from the very start of learning performers can guide their actions in relation to this information and the informational constraints present.

Practice of skills under specific constraints and the appropriate information is essential in the development of expert performers. Expertise may be eventually developed when practice is conducted in the presence of specifying information and constraints, resulting in the development of functional information-movement couplings to use in competition settings (Jacobs *et al*., 2001). An expert performer has greater flexibility and increased ability to adapt to movement constraints in a variety of situations. This ability is developed through practice in a variety of settings and the opportunity for performers to develop movement solutions under realistic task constraints. Although often viewed as noise or error, variability is actually the ability of a performer to modify their movement according to the constraints present. Functional variability is important for flexibility in dynamical systems and allows performers to adapt more efficiently to potential perturbations within the system (Button *et al.*, 2003). The idea of a 'perfect' technique is argued to be inaccurate when expert performers who have practised the same task for many years cannot reproduce the exact same movement within competition. This inaccurate idea of a perfect technique in experts is highlighted by (Schoellhorn & Bauer, 1998) who found variability in the movement pattern of discus throwers during both practice and competition. Open-skill sports require functional variability to adapt

to constantly changing environmental variables. Therefore, experts in these sports need to acquire this functional variability to be able to conduct skills under a range of constraints.

In water polo a 'perfect' technique is thought to exist for the shot at goal. In order to develop this 'perfect' technique a large amount of practice time is devoted to closed-skill practice of the water polo shot. The biomechanical technique of the water polo penalty shot has been examined by a number of researchers (Ball, 1996, 2004; Clarys *et al.*, 1992; Clarys & Lewillie, 1970; Davis & Blanksby, 1977; Elliott & Armour, 1988; Feltner & Nelson, 1996; Feltner & Taylor, 1997; Leach *et al.*, 1985; Whiting *et al.*, 1984). However, none of these studies have included a defender and only Davis & Blanksby (1977) included a goalkeeper. Therefore, it would appear to be important to determine what impact a more realistic game environment has on water polo shooting. Changes in shooting performance due to the presence of the goalkeeper and/or defender may have important implications for the design of practice in water polo.

The aims of this study were, therefore, to examine the effects of altering the environmental constraints on water polo shooting performance. Specifically, the focus was on examining the effect of the presence or absence of a defender and goalkeeper on the ball speed, accuracy and technique of the water polo shot. The accuracy variables (success of shot, score out of five and ball placement in the grid accuracy system) will determine how the presence of the defender and goalkeeper alter the number of successful shots and the placement of the ball in the goal. The effect of the defender and goalkeeper on technical aspects of the water polo shot such as: angles at release of the trunk and shoulder; linear variables such as height of release and forward swing distance; and temporal measures of phase durations will also be investigated. Angles at release are expected to increase in the presence of the constraints in order to gain better shooting options around the opponents and to assist in the development of ball speed. Linear variables are expected to increase also, to assist in gaining more ball speed and movement around the opponents. The duration of the shot and subsequent phases of the shot are also expected to also increase as the speed of the shot increased to shoot the ball faster past

the opponents. These findings may allow a clearer understanding of the appropriate practice conditions needed to improve water polo shooting in game situations where the defender and goalkeeper are present.

## Thesis Purpose

The general purpose of this thesis was to determine the effect of game specific task constraints (in the form of the defender and goalkeeper) had on shooting accuracy, selected technique variables (angles at release, linear and temporal measures) and speed of the water polo shot.

## Thesis Aims

The specific aims of the thesis were to:
1. Examine the effect a defender and goalkeeper had on accuracy and ball speed;
2. Determine if the presence of goalkeeper and defender altered technical aspects of the water polo shot (i.e. angles at release, linear and temporal measures).

## Thesis Significance

The importance of developing the 'perfect' technique has generally dominated sports practice. The majority of practice time is designated to the practice of closed skills in order to develop this 'perfect' technique. Water polo is one sport that demands a lot of practice time spent on the development of the perfect shot technique. However, this practice is often misrepresentative of actual game conditions. The ecological approach emphasises the practice of skills should be conducted in the presence of game-specific constraints. Such practice allows a player to develop the link between the information present in the environment and their corresponding actions. By practising under a range of constraints specific to game-play, a beginner can develop solutions to a range of movement problems. Therefore, this study will aim to investigate how game-

specific task constraints in the form of the defender and goalkeeper will influence shooting outcome and technique. This may identify appropriate practice conditions that will improve water polo shooting resulting in improved shooting in game situations.

## Hypotheses

- The presence of the defender and goalkeeper will cause the shooter to produce a larger ball speed in order to minimise the opportunity for a save;
- The presence of the defender and goalkeeper will result in a decrease in the number of successful shots achieved and make the placement of shots more variable within the goal;
- The presence of the defender and goalkeeper will decrease the shot movement duration, as the ball will be travelling at an increased speed;
- The technique of the shot will be altered due to the presence of the defender and goalkeeper resulting in changes to the various shot kinematics.

## Thesis Limitations and Strengths

The author notes and acknowledges the following limitations and delimitations within this research project:

1. Due to the subject inclusion criteria (competitive level male water polo players from only one regional club), the findings of this research may only be applicable to players of similar standards;
2. The sample size of ten participants which may limit the ability to detect statistical significance for smaller effect sizes;
3. For each participant the research was conducted only at one time near the end of the player's competitive season. These findings, therefore, cannot be inferred to any other time of the season;
4. Testing sessions were conducted in the player's normal training setting and although inclusion of some game-specific attributes was attempted,

the situation may still have inferred a laboratory-type 'feel' in terms of restrictions on the players;

5. Recent rule amendments by FINA have extended the penalty line to 5m in water polo. This study investigated the water polo shot from the 4m-penalty line (previous rules and current at time of testing) and findings are, therefore, limited to this specific distance;

6. A two-dimensional (2D) analysis was used rather than a three-dimensional (3D) analysis, which would have been more applicable to the rotations inherent to the throwing motion;

7. The use of high-speed video would have provided more accurate representation of the movement by providing more frames per second.

# CHAPTER 2: REVIEW OF LITERATURE

## Introduction

This review of the literature will examine the current standing on the existence of a perfect technique in sport. The influence of ecological psychology on the rejection of the 'perfect' technique is discussed in relation to the central idea that perception is linked to action. This viewpoint emphasises that practice should be representative of the competition environment in order to develop movement solutions under the constraints inherent to competition. The process of learning and the characteristics an expert attains are also discussed in relation to ecological psychology. Throughout this thesis, the water polo shot is then used as the task vehicle to examine the effect of task constraints on motor behaviour and what implications these constraints may have on how water polo practices are structured.

## Development of Expertise

Expertise in sport is the goal for a large range of athletes. There are a variety of ideas on how to assist athletes to develop to this level. Current research identifies that the amount of practice conducted over an athlete's career is a key determinant of ultimate performance level (Ericsson, 2003). In particular, the use of deliberate practice to improve certain aspects of performance is the most beneficial. Initial studies by Ericsson and colleagues (1993) found that expert violinists had spent over 10,000 hours on practice, which was 2,500 – 5,000 hours more than the less accomplished experts of the same age. In addition the best expert violinists spent more time in solitary practice in comparison to the other experts, therefore spending solitary practice time on improving specific aspects of their performance. The use of solitary practice is directly applicable to performances of representative tasks in solo situations such as music, darts and individual sports.

Time spent practising for team sports in comparison, is more complex due to the inclusion of team-mates within practice and the requirements on a player due to the range of situations an athlete must perform in during competition. Team sports such as hockey and soccer showed that at approximately 9 years

into their career athletes became more involved in team practice and decreased their time spent in individual practice (Helsen *et al.*, 1998). A strong relationship was once again found between deliberate practice, both individual and team, and the level of performance or expertise attained. Therefore, the amount of practice has been shown to be an important indicator of eventual expertise.

Although the amount of practice has been identified as a major predictor of expert performance, very few studies have examined the most effective ways to structure the practice environment for development of expertise through efficient learning. Studies on practice have centred on specific strategies, for example the relative effectiveness of blocked and variable practice. Blocked or constant practice is when a skill is practised in a similar way continuously without any variability of the conditions, whereas variable practice incorporates variety in the practice of a skill across many differing conditions. The benefit of variable practice is that a performer develops the ability to perform the skill in a variety of future competition situations. The benefit of variable practice on the basketball free throw was found when compared with constant practice (Schoenfelt *et al.*, 2002). Although both groups improved over the three weeks of practice, during the post-test the variable practice group performed better than their pre-tests, while the constant practice group regressed to their pre-test level of performance.

Inclusive of practice variability is the practice strategy of closed versus open skills. A closed skill is defined as "a motor skill performed in a stable or predictable environment where the performer determines when to begin the action" (Magill, 2003 p. 9). A closed skill, therefore, requires the player to attend to the technique of their movement whereas an open skill requires them to attend to both their technique and their surroundings (Magill, 2003). As a consequence closed skill practice is supported by the idea of the player being able to practise with reduced attentional load. This reduced load allows the player to focus entirely on their movement without the pressure from the opposition being present. As a result there is a reduction in the load on the information-processing system, a system that has discrete limitations on how many activities can be performed simultaneously (Magill, 2003). The use of this

closed skill practice method of skill learning results in a greater degree of successful performance of the skill for the player.

In contrast, open skills in competition are unique and often involve athletes having to produce movements that he/she has not conducted in that way anytime before. Movements previously practised are usually modified to achieve the outcome goal of the situation (Magill, 2003). Open skills are generally present in competition environments. Therefore, practice time should incorporate similar competition situations within practice so athletes can develop experience in these open skills. Open skilled practice includes such skills as the return of a serve in tennis or shooting in water polo with defensive players and the goalkeeper present. In comparison closed skills are such tasks as performing free throws in basketball, hitting a ball off a tee or shooting in water polo against an empty goal.

The importance of specificity in practice was addressed by Proteau (1992), who suggested that learning could not progress to higher levels if the relevant visual cues were removed from the learning environment. There has been equivocal findings in the area of vision and skill acquisition in relation to practising in specific environments where visual stimulus is present. When skilled and unskilled catchers were compared, vision was found to be helpful for the skilled performers but not essential whereas the visual stimulus was essential for the unskilled performers (Williams *et al.*, 1999). When vision was occluded during the task of crossing a balance beam experts were not as disrupted by this constraint as the novice performers (Robertson & Elliott, 1996a). These findings suggest that the experts have a broader base of learning which encompasses a range of sensory experiences that assist in completion of the task. This finding brings to light the effect of previous learning may have on research where practice is manipulated. These results lead to the study of performers with no gymnastics experience who were asked to complete a dynamic balance task (Robertson & Elliott, 1996b). Performers were assigned to groups of either no vision or vision practice. The no vision groups had a larger amount of error in practice than their vision counterparts. However, in the post-test when vision was occluded, the full vision practice group had difficulty with the task. This finding supports the idea that vision is important in learning but is not essential.

Other sensory components of a skill should also be addressed, as these sources of information are also important. Despite these learning strategies resulting in some improvement of skills, the influence of the practice environment on skill acquisition is relatively unknown.

## The 'Perfect' Technique

The coaches' role is to develop a practice environment that improves an athlete's skill of particular tasks to perform optimally in competition. Coaches have long understood that in order to develop expertise, an athlete must spend a large amount of time practicing the skill. Research has shown that large amounts of practice have a positive relationship with the level of performance achieved (Ericsson, 2003; Ericsson *et al*., 1993; Helsen *et al*., 1998). Based on these findings, some coaches may incorporate an excessive amount of closed skill practice to reach a so called 'perfect' technique, which in turn could potentially have a detrimental effect on an athlete's performance in competition.

Opposition to the idea of a 'perfect' technique has surfaced progressively in the area of motor learning. Glazier and David (2005) questioned the existence of the ideal golf swing, emphasising that variability between an individual's swings may be the golfer attempting to satisfy the surrounding constraints which are impinging on their performance. While there may be a common coordination pattern with the golf swing, coaches attempting to develop a 'perfect' swing should instead focus on the constraints that influence the golfer the most and attempt to develop solutions to these impinging constraints. So rather than mimicking a pro-golfer's movements, a player may be better off to explore a range of swings under potential perturbations from the environment or competition settings to develop their own stable swing (Knight, 2004).

## Ecological Psychology

Recent applied research from the ecological psychology approach has shown that practice conditions should be representative of the competition environment if optimal learning is to occur (Araujo *et al*., 2004; Renshaw &

Davids, 2004; Renshaw *et al*., 2004; Savelsbergh & van der Kamp, 2000; Williams & Hodges, 2004; Yi *et al.*, 2005). Therefore, the value of the reductionist approach where decomposed skills are performed in practice is being questioned.

Ecological psychology is the multi-disciplinary approach to the study of biological systems and how information transactions occur between the biological system and their environment (Oudejans, 1996). This approach incorporates animal-environment mutuality and the idea that perception and action are coupled. This idea demonstrates how the animal cannot live outside its natural environment, such as a fish out of water or a sporting example such as a water polo shot out of the water. Perception and action are also linked as information or perception is determined by the actions present within an environment. Therefore, animals are linked explicitly to their environment through everyday activity. These links demonstrate how these inseparable components represent a complex biological system. Biological systems are incredibly complex due to the multiple components and potential interactions that can occur between the individual and the environment or between individuals. These complex interactions further demonstrate why biological occurrences such as motor skills cannot be assessed through a mono-disciplinary approach. Rather, a multi-disciplinary approach is far more applicable in the study of biological systems and motor tasks.  Constant interplay between the animal and their environment must occur to maintain a stable dynamic system in which the animal can survive and function in an optimal manner (Oudejans, 1996).

The main focus of the ecological approach is the identification of what information guides actions and how perception of this information enables action (Bootsma, 1988). Information can be in the form of optical, auditory or other means. These information flow fields specify movement within the environment (Kelso, 1995). The level of an individual's awareness to these flow fields dictates if the relevant cues for movement are detected. The ability to detect information is perception, the information present in the flow fields of an environment hold the potential possibilities for action (Bootsma, 1988).

# Perception-Action Coupling

One of the central ideas of ecological psychology is perception-action coupling. This idea is a cyclic concept demonstrating how information is obtained by the performer from the surrounding environment and is then used to adapt and conduct actions according to the information perceived. Expert performers are able to use the information present in their environment during skills to change their movement throughout the task according to the constraints present (Williams *et al.*, 1999). For example continuous perception-action coupling has been found to occur in locomotor pointing tasks such as bowling in cricket. Cricket bowlers made adjustments early and late in their run-up so that their front foot lands close to but not over the popping crease (Renshaw & Davids, 2004). Regulation of the task occurred throughout the whole of the entire run-up, showing that the visual information provided allowed the bowlers to adjust their run-up throughout the task to meet the constraints present. This continual perception-action coupling was also found with one-on-one basketball dribbling with the goal of getting a basket (Araujo *et al.*, 2004). The symmetry between the attacker and defender is broken when the attacker attempts to dribble past the defender to score. As the decision is made by the attacker to dribble past the defender, the system stability is disturbed; the attacker continues to try to maintain the disruption while the defender attempts to find symmetry again. This continual movement provides information to both the attacker and defender on how to achieve their goal relative to the movements occurring between the dyad.

Similar to perception-action coupling, is that information obtained from the environment is tightly coupled to individuals' actions. Active exploration of the optic array provides information on the environment and the individuals' own movements, thus providing information to guide the individuals' own actions. The term information-action coupling evolved from this view of the perception-action coupling (Savelsbergh & van der Kamp, 2000). In order for performers to use information-action couplings, practice conditions should introduce the constraints and through repetitions in practice find the appropriate solutions needed to perform the task. To develop a functional skill to an expert level many practice sessions over many years may need to occur. Expert cricket

batters who have spent many years practising have developed strong information-action couplings and was observed when real bowlers were compared with a bowling machine (Renshaw *et al.*, 2004). Batting against a bowling machine significantly altered the batters coordination and timing of the interceptive skill. Over many years of practice with a real bowler the skilled batters had learned to use the body actions of the real bowlers to initiate their movements and timing. However, in the presence of the bowling machine, these information-movement couplings were broken which resulted in a reorganization of the batters' movement thus altering their coordination and timing (Renshaw et al., 2004). Practice should, therefore, be representative of competition conditions so that information-movement couplings can be developed to find solutions to the constraints present.

**The Constraints-led Approach**

The constraints-led approach was developed by Newell (1986). This model demonstrated how coordination and control of motor tasks is influenced by a range of constraints. The model was later refined by Newell and McDonald (1994) to incorporate the perceptual motor work space. As can be seen in Figure 2.1, the three constraints guide the self-organization of the system to an attractor state in order to achieve the coordination and control of the goal movement (Williams *et al.*, 1999).


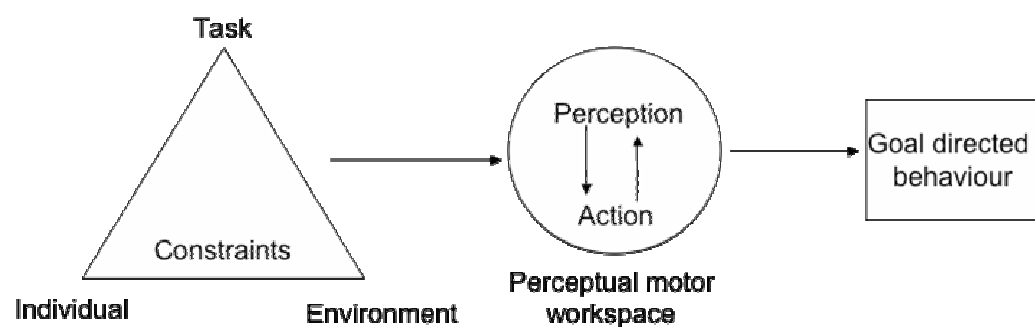
**Figure 2.1. Constraints-led approach to skill acquisition**
(adapted from Newell & McDonald, 1994)

The three constraints are individual, task and environmental. Individual constraints include personal characteristics such as height, mass, body

composition and genetics. Physical, cognitive and emotional aspects of individuals also contribute to this type of constraint. These include cognitive aspects such as patterns of thought, practice level and physical aspects such as defects in vision as well muscular aspects such as strength and flexibility. Emotional aspects such as anxiety and motivation in any given situation also contribute to individual constraints (Williams *et al*., 1999). Task related constraints include the goal behaviour, rules of the sport, tactics or strategy used in the sport or the implement used (Williams *et al*., 1999). Task constraints are the only type of constraint that is able to be manipulated within the practice environment to improve performance and, therefore, the important constraint around which to structure practice in order to make practice similar to competition. On the other hand environmental constraints are in the form of energy flows and information from visual and auditory means that surround the performer of the motor task and provide information that is perceived as a constraint and ultimately a solution is reached to achieve the goal directed behaviour (Williams *et al*., 1999).

Constraints are influential factors within the practice environment and performance environments that act on the acquisition of movement coordination (Newell *et al*., 2003). Constraints are not necessarily negative influences on movement behaviour, but represent the way that movement system components are integrated to form specific types of functional organisation. (Chow *et al*., 2006).

For stability to be achieved by a system in the presence of constraints, attractor states must be discovered and developed through the use of the perceptual-motor workspace. The perceptual-motor workspace is where solutions are developed and explored so that the appropriate solutions to movement problems can be determined. As constraints emerge within a system, phase transitions occur in an attempt to return the system to a stable state (Magill, 2003). As solutions are formed to satisfy the constraints present in the environment, an individual is able to reach solutions to the movement problem. This decaying of the constraints present results once again in a stable system until the emergence of new constraints occurs and the cycle repeats (Guerin & Kunkle, 2004). A dynamic system is therefore able to self-organise; resulting in

the emergence of a specific and stable pattern for a particular behaviour or movement (Magill, 2003). Self-organization uses the energy flow within the system to obtain stability for functional purposes such as performing motor skills in the presence of constraints (Williams *et al*., 1999). The ability to adapt to complex systems occurs in practice through the use of individual-individual and individual-environment interactions (Guerin & Kunkle, 2004). This study further supports the view that practice conditions should be structured to involve a range of individual and environment interactions similar to competition in order to develop the ability to use information to solve movement problems.

## Process of Learning

The development of expertise is an explorative learning process, which evolves over time with many hours spent in practice. Learning is the change in the capability of an individual to perform any given skill and this change should be a permanent performance improvement that results from practice and/or experience (Magill, 2003). For competition preparation athletes should, therefore, participate in practice conditions that will provide them with the experience needed for competition. Consequently it is the role of the coach to provide a well-structured practice setting that incorporates practice of game specific conditions. This type of competition specificity in practice allows players to select and attune to information needed to emerge from impinging constraints and develop the information-movement couplings needed for competition (Savelsbergh & van der Kamp, 2000). Increased variability in practice allows for multiple information-movement couplings to be developed, further preparing athletes for competition settings where a variety of constraints are present (Savelsbergh & van der Kamp, 2000).

Information-movement couplings must also be functional; which requires beginners to attune to specifying information rather than non-specifying information when learning a skill. Evidence suggests that beginners often attune to non-specifying variables which still result in an accurate performance (Jacobs *et al*., 2001). However in the long-term their skill level is actually restricted because they had not attuned to the specifying information that would have resulted in a better performance (Jacobs *et al*., 2001). Initial practice for

beginners should, therefore, have specifying information present so that beginners can guide their movement according to the information and constraints present.

The process of learning can also be said to be a result of mastering the redundant degrees of freedom present. The degrees of freedom (or biomechanical degrees of freedom) refer to the joints involved in a motor skill and the number of orientations or movements of those joints involved. While learning, the number of redundant degrees of freedom can be reduced to help develop coordination, lessening the complexity of the motor system to support goal directed behaviour while being learnt (Glazier *et al.*, 2003). In comparison an expert performer who is more practised in a particular motor skill can freeze and release degrees of freedom dependent on the constraints present, whereas novice performers tend to freeze and couple joints to cope with complex dynamical systems (Button *et al.*, 2003). The freezing or freeing of the degrees of freedom according to the constraints is part of the learning process. Ultimately learning involves developing a stable movement (whether this is with more or less degrees of freedom) that results in the goal outcome when a variety of constraints are present.

In comparison, evidence suggests that early disorder and instability in a movement system can lead to increased structure formation and maintenance of order in latter stage of development (Guerin & Kunkle, 2004). This evidence is supported by the theory that system organization is driven by the constraints present in the environment and, as conditions are added, reorganization occurs. Therefore, if practice incorporates a variety of constraints during initial practice, the constraints will decay as the performer develops solutions to those constraints, thus developing a variety of constraint solutions to movement problems that will provide a performer with more solutions to use in competition situations. If a 'perfect' water polo shot is developed during practice in line with previous methods of practice strategies and without any opposition players present, within a game situation this 'perfect' shot may not be successful. The shooter would be familiar with shooting at an empty goal, but within a game situation the defender(s) and goalkeeper will be attempting to block the shot of the shooter. The shooter may, therefore, have difficulty shooting around the

opposition into the goal, because this type of shooting has not been practised previously. Accordingly, early introduction of opposition will allow shooters to alter their movements according to the constraints present.

## Expert Performers

Expertise is developed over a long period of time when practice is conducted in the presence of specifying information and constraints. Forming functional information-movement couplings for use in competition settings consequently develops expertise. A key attribute of an expert is the ability to adapt to constraints in a variety of situations. This enhanced flexibility stems from variable practice in a range of competition constraints.

Increased flexibility and adaptability within a movement is referred to as functional variability. Inter-trial variability is often referred to noise or error across repeated trials of a movement (Davids *et al.*, 2004). In contrast, functional variability is the ability of a performer to slightly adapt their movements to the surrounding constraints in order to reach the goal outcome. This flexibility is important in dynamical systems as they are susceptible to perturbations and expert performers need to be able to adapt to these instabilities to perform the goal movement (Button *et al.*, 2003). Elite athletes who devote years of practice to a skill cannot reproduce consistent movement patterns in practice or competition. This finding was highlighted when discus throwers were examined, revealing a cluster effect across practice and competition sessions. Although they had similar movement patterns within a single practice or competition session, between practice or competition sessions there was variability in the movement pattern of the throw (Schoellhorn & Bauer, 1998). These results indicate that even elite athletes cannot reproduce an identical movement continuously across practice and competition. A difference in variability between international and national level athletes has also been found. International level discus throwers exhibited a greater amount of variability in their throws in comparison to the national level throwers (Bauer & Schoellhorn, 1997). Differences in variability are also found between skilled and unskilled performers. Skilled pistol shooters exhibited increase variability in the shoulder and elbow joints. This increased movement

in these joints allowed the wrist to be stabilised so there was less variability in the outcome of the shot (Scholz *et al.*, 2000). Unskilled shooters however had more variability in the wrist resulting in more variability in the outcome shot.

In contrast, a number of studies have not shown any significant differences in the amount of inter-trial variability for athletes of varying skill levels. When expert and novice long jumpers were compared, similar variability in the task of jumping from the take-off board was found during different parts of the run up. Similar inter-trial footfall variability was found in relation to the take off board and during the final four strides of the run up between the two skill levels (Scott, 2002). Visual control altered the stride length in order to remove the initial inconsistencies in the stride length found in the run up in order to hit the take off board. This alteration in stride length immediately prior to task completion is an example of an information-action coupling overcoming the task constraints present to reach the goal outcome by functionally changing the movement to adapt to the environment. A higher skill level lead to increased inter-trial movement consistency of the elbow and wrist joints in the basketball free throw (Button *et al.*, 2003). The authors predicted that angular motion of these joints compensated towards the end of the throw for the subtle changes in the ball release parameters. In contrast to previous studies discussed, the basketball free shot variability decreased as a function of increasing skill. However, in this study participants were not completing this skill under the potential pressure that would be present in a game situation, which could have potentially altered the amount of variability that occurred in these free shots.

Generally, successful performers in open-skill sports need this functional variability in order to adapt to the changing environment within competition and the increased attentional demands on the performer due to the constraints present while still attempting to reach the goal outcome. Increased movement flexibility and the ability to adapt to constraints is a result of practice under specifying information and competition specific constraints.

Often research is preoccupied with either the outcome of a skill or the movement or technique of the skill. Seldom are the two combined to determine the skill as a whole. Due to the growing evidence of functional variability,

especially in expert performers, the need for more research into the movement patterns and resulting outcomes are needed. A recent study on constraints placed on a soccer-chipping task demonstrated that the constraints caused alterations in the coordination pattern of the kick. However, with practice under these constraints, the success of the task goal improved despite the coordination pattern adapting to the constraints (Yi *et al.*, 2005). Changes in the movement pattern were also found in a study on pistol shooting by Scholz and colleagues (2000), where large amounts of variability in the associated joints allowed for a more consistent outcome of the shot. These studies demonstrate how expert performers may be variable in their movements but that this flexibility allows them to adapt to the constraints present, ultimately allowing a more consistent outcome of the skill a majority of the time. Similar studies into the movement patterns and outcome of a variety of skills is needed to help sports scientists and coaches alike to develop practice situations that will achieve expert performance.

## The Game of Water Polo

Water polo is one of the five FINA (International governing body for aquatic sports) aquatic sports. The game of water polo requires players to swim long distances at a moderate to fast pace, with frequent sprints required to get into position or to avoid opponents (Smith, 1998). This repetitive swimming requires players to have good aerobic endurance and repeated sprint ability (Mujika *et al.*, 2006). Players must be able to tread water throughout the game without the use of the hands so they are free to fend off opponents and for ball handling. The eggbeater kick is used to tread water while the eggbeater boost is used to gain maximum or extra height (Sanders, 1999). Players need good eggbeater endurance and explosive power to gain maximum height out of the water in the eggbeater boost. Skills in passing and throwing are also vital because accuracy and the ability to produce high velocities are also valuable during the game for shots at goal. Water agility or the ability to change directions quickly and effectively during the game is necessary to avoid or mislead opponents.

## Rules of the Sport

Water polo is played in a 30m by 20m pool for male games and a 25m by 20m pool for females that is a minimum of 1.8m deep. Seven players including the goalkeeper line up on opposite ends of the pool with the ball in the centre. When the referee blows the whistle, the game begins with the players sprinting for possession of the ball. The game consists of four periods of eight minutes actual playing time with two minutes interval for the first and third break and a five-minute interval for the second break. Each team has six reserves who can be substituted during the game.

FINA re-assesses all aquatic sport rules and procedures biannually and following a recent rule amendment this year (2005) the rules have changed in the hope of developing a faster game and encourage more shooting at goal. The main implication of these rule changes to this study is the change of the penalty line. It was previously at 4m from the goal and has now been changed to 5m following rule amendments.

## The Water Polo Shot

Most water polo throws utilize the overhead throw pattern where the ball comes from behind the body and is brought up and over the head and released in front of the body. The goal of this overhead throw pattern is to achieve high endpoint velocity. The kinetic link principle is utilized with the water polo throw where the hips initiate rotation, the trunk turns towards the target so that the momentum generated from these proximal segments is transferred through the arm, maximizing the ball velocity (Ball, 2004). The kinetic link principle is a model linking segments by external torques. These torques produce resultant acceleration of that segment, which leads to a lagging behind of the end segments that are then required to 'whip' forward to catch up with the proximal segments of the model, resulting a high endpoint velocity (Kreighbaum & Barthels, 1996). Consequently the greater amount of momentum occurring at each segment, the greater the velocity reached at each segment and the overall greater effect on the velocity of the throw.

The water polo shot is described in detail by Ball (2004) and Alexander and Honish (2005). The ball starts behind the body with the player looking at goal. The ball is picked up and the hips are bent over as the legs rise up to perform an explosive boost movement. At the top of the back swing, the hips are starting to rotate forwards toward goal, the shoulder line points towards goal as the hand moves behind the ball and the opposite arm is moved up to provide balance for the rotation at the shoulders. In the middle of the forward swing the hips have completed the rotation towards goal. During this phase the velocity of the shoulder rotation is at its peak and the arm is externally rotating with the elbow flexed and the forearm lagging behind. The upper body is also moving forwards for additional transfer of momentum. At release, the elbow rapidly extends and the wrist flexes as the ball leaves the palm. The opposite arm is rapidly brought down to the side to increase shoulder rotation. The continuation of the arm movement across the body and internal shoulder rotation post-ball release in the follow through is important to reduce injury risk. During the follow through the elbow does not straighten completely.

Figure 2.2 displays the important factors in the performance of a maximal velocity water polo throw. While the mass of the ball is not overly high, air resistance could be proportionately high due to the relatively large surface area of the ball. Velocity at release is influenced by many factors, some which have been well researched. Angle of release has not been quantified and would be specific to the shot, height out of the water and the position in front of goal. Height of release is dependent on the stature of the athlete, the length and position of the arm during the shot and the height out of the water an athlete could attain via the egg beater boost (Sanders, 1999). Although maximum height out the water has not been linked to velocity of the ball, an optimal height may exist (Davis & Blanksby, 1977; Elliott & Armour, 1988). Speed of release is directly determined by the product of angular velocity and lever length. Angular velocity of the arm during the shot has been identified, although further studies are needed to confirm these optimal values. Moment of inertia and utilisation of the kinetic link model determine the angular velocity. The segments used during the throw and their phases have also been identified during the throw. Limb lengths have been assessed and may be linked to the velocity of the throw. Range of motion of the shoulder has not been measured on water polo players.

However, it has been identified that the ligamentous structures of the shoulder are stressed during the shot (Feltner & Taylor, 1997), possibly indicating the large range of motion inherent to the shoulder joint in water polo shooting as performed by elite players.
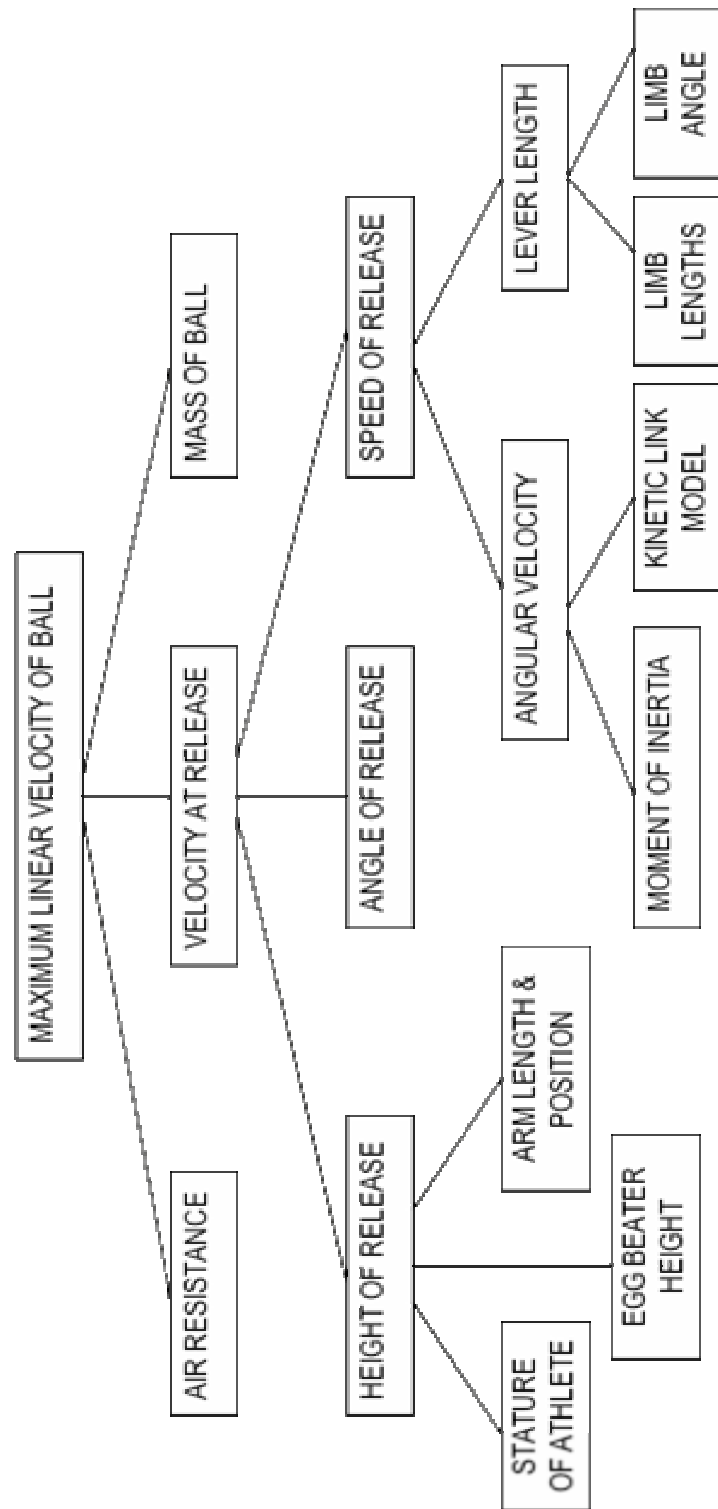
**Figure 2.2. Throwing model for maximum velocity**

Kinematics of the trunk and arm have been described for the water polo penalty shot (Davis & Blanksby, 1977; Elliott & Armour, 1988; Leach *et al*., 1985). There was a significant difference in the angle of the upper arm to the vertical at the rear point in the back swing, horizontal displacement of the head from the rear point to release and the horizontal displacement of the ball centre relative to the vertex of the head during the overhead shot comparison of national and club level players (Davis & Blanksby, 1977). These findings suggest that the greater shooting speed of national than lower level players may reflect the national players' increased ability to use lateral trunk flexion and increased range of motion at the shoulder joint. Greater elbow flexion and external humeral rotation have also been linked with increased ball velocity (Leach *et al*., 1985). There appears to be a general lack of wrist flexion contribution to the throw velocity. This lack of wrist flexion is possibly due to the relatively larger ball used, in that some players would have an inability to grip the ball adequately to achieve the required ball control (Elliott & Armour, 1988).

One study observed female water polo players' throws. Although the kinematics were similar to males, their ability to grip the ball led to slight changes such as the path of the back swing (Elliott & Armour, 1988). This path was more vertical than horizontal as was found in the males and the movement was also not as continuous as the males because it included more frequent periods of acceleration and deceleration (Elliott & Armour, 1988). These periods of acceleration and deceleration may indicate that the female players had a relative inability to effectively utilise the kinetic link principle to pass momentum through each of the segments and that this contributed to their reduced endpoint velocity.

Ball control in water polo and the shot is vital in the game. This control is linked to the ability to grip the ball, which is important in the back swing and therefore the corresponding forward swing and thus release velocity in the water polo throw. It was not stated whether female FINA regulation sized balls were used in the Elliott & Armour (1988) study, presumably the male regulation sized balls were used and hence the difficulty in the female subjects' ability to grip the ball. Male regulation sized balls are 0.68 – 0.71m in circumference in comparison to

the females' size which is 0.65 – 0.67m, therefore smaller and easier for the female player to grip for ball control.

When club players were compared to national representatives the ball speed achieved ranged from 15.0 m.s$^{-1}$ and 19.4 m.s$^{-1}$ respectively, with the national level players having a significantly greater ball speed (Davis & Blanksby, 1977). Similarly, national level players from the USA obtained an average speed of 19.7 ± 0.4 m.s$^{-1}$ (Whiting *et al.*, 1984). These ball speeds have also been found in national level players (18.4 m.s$^{-1}$) and college level players (13.7 – 18.9 m.s$^{-1}$) (Elliott & Armour, 1988; Feltner & Taylor, 1997). The speeds in the water polo throw are approximately half the velocity when compared to the baseball pitch where the highest recorded ball speed was 45.1 m.s$^{-1}$ (Hjermstad *et al.*, 2004). The water polo throw is often compared with the baseball pitch due to the similarities in the kinematics of the movement. The differences in speeds achieved between the two movements are primarily due to the size (and hence air resistance applied) of the water polo ball, the lack of ground support and hence ground reaction forces and the resistance of the water to hip rotation during the water polo shot. The larger mass of the ball indicates greater velocity is needed to propel the object and the lack of ground support implies a decreased ability to apply force to the shot through contact with the ground.

The speed obtained in a water polo throw has been found to result from trunk rotation (hip and shoulder rotation) 30 – 35%, internal rotation of the shoulder and/or horizontal adduction of the arm 20 – 30%, elbow extension 20 - 27% and wrist flexion 8 -13% (Ball, 2004). The throw involves spinal rotation and lateral spine flexion, humeral medial rotation, forward arm extension and pronation and hand flexion (Leach *et al*., 1985).

In Clarys, et al (1992) the accuracy of water polo shots was determined from the 4m and 8m marks. Impact force associated with shots from these distances was also calculated. Water polo shots were more accurate from the 4m distances, where six out of the ten participants threw 100%. Whereas the 8m distance resulted in an accuracy of 37 – 75% for all participants. When accuracy of the water polo throws decreased by 30% there was a decrease in ball impact force on average of 157N. The 4m distance shot using an overhead

throwing technique had an impact force ranging from 598N to 981N, while the 8m distance shot had an impact force ranging from 402N to 961N (Clarys *et al*., 1992). The decrease in impact and accuracy from the 8m distances indicates that there is a reduced chance of a successful shot at goal if the distance increases. Therefore, when scoring, the player should aim to be as close to the goal as possible. During a game situation the centre forward and wing players will aim to be positioned as close to the two-metre line as they can get. If they go past the two-metre line without the ball they are deemed offside and a turn over occurs.

### *Contribution from lower body*

The skilled players utilised their legs more during the shot, producing more force as the body moved upwards by flexing and extending the legs. The trunk also contributed in the shot through leaning and twisting as the ball was released (Kaga *et al.*, 1986).

The vertical displacement of the player during the shot was influenced by the method of ball pick-up off the water surface. The club players generally held the ball in their hand or lifted the ball from underneath whereas the national level players took the ball off the water from above the ball which involved pushing the ball down slightly then rotating it so the hand was under the ball as it was lifted off the surface of the water (Davis & Blanksby, 1977). These methods of ball pick-up were also found by Elliott & Armour (1988), with the push rotation lift technique also resulting in increased ball velocity. There does not appear to be a strong relationship between height out of the water and throwing speed, perhaps suggesting that there is an optimal height rather than a maximal height out of the water to maximise the speed of the shot (Davis & Blanksby, 1977; Elliott & Armour, 1988). Possibly the water around the lower body acts to stabilise the upper body during the throw and if the player is too far out of the water, he/she doesn't have this stability provided by the water.

### *The Water Polo shot in the Game*

Within water polo many different techniques or types of shots can be used during the game to score. The fast shot or overhead shot used predominately in water polo was compared with the delay shot which is used primarily to deceive

opponents and the goal keeper by giving the illusion that the opportunity to shoot has passed. The better performer of the two subjects had an 18.1 m.s$^{-1}$ ball speed of the delay shot and a 21.2 m.s$^{-1}$ ball speed of the fast/overhead shot. The delay shot had a uniform speed during the first part of the forward swing. Then, once a point was reached there was rapid increase in speed to release. This change requires more contribution from the shoulder internal rotators to develop the ball speed whereas the fast/overhead shot utilises the trunk rotation more to generate ball speed (Ball, 1996). The use of the delay shot will deceive the defenders and goalkeeper into acting early to block the shot which will allow the shooter to react to their movements and therefore have an advantage in shooting possiblities.

Another technique called the sweep shot was compared with the overhead technique. The sweep technique utilises more of a horizontal adduction movement where the ball sweeps from behind to front and is predominately used when players are weaker in internal rotation (Ball, 1996; Feltner & Taylor, 1997). The chest, upper arm and forearm girths were moderately correlated with internal rotation contribution and ball speed at release further suggesting the use of the sweep technique by weaker players. The overhead technique requires more strength of the internal rotators and shoulder adduction whereas the sweep technique requires more contribution from the horizontal abductors. Utilising the sweep technique decreases the risk of injury due to the decreased reliance on ligamentous structures of the shoulder and elbow. However, overhead technique does predict a positive moderate relationship with ball speed at release. The differences in ball speed between the two types of shots were not provided (Feltner & Taylor, 1997).

Alternative types of shot to the overhead style have been identified which can be used in suitable game situations are the back and push shot (Clarys & Lewillie, 1970; van der Wende & Keogh, 2005). The back shot, if performed effectively, can be a useful offensive weapon with a large element of surprise. However, this type of shot has not been widely studied. Clarys and Lewillie (1970) briefly commented on the movements of this shot and the low resulting accuracy of 27.3%. The back shot starts with the player's back to the goal. As the ball is lifted off the water surface, an egg beater boost is performed and as

the ball lifts sideways, the arm abducts with a bent elbow to reduce the moment of inertia around the shoulder. The player rotates towards the goal with the elbow and forearm lagging behind with the ball. When the arm reaches a fully abducted position and the body is slightly turned towards the goal enabling the player to view the goal, the elbow extends and the wrist and fingers flex as the ball is released (Clarys & Lewillie, 1970; van der Wende & Keogh, 2005). This shot provides a large element of surprise and therefore decreased ability for the opponents to react in time to block the shot. The decreased accuracy due to the curvilinear path of the ball and the difficulty in performing the shot due to the lack of vision of the target suggests this shot should be used minimally and only for certain situations and where possible a more accurate shot should be used.

The push shot must be executed at high swimming speeds when a swim off from an opponent has occurred (van der Wende & Keogh, 2005). There is little information available on the movements and outcome of this type of shot. Clarys and Lewille (1970) found an accuracy of only 50% when the push shot was performed during their study. The push shot requires the player to be in a front crawl position. He/she swims at full speed while dribbling the ball towards the goal. Close to the goal, the ball is pushed under the water slightly allowing the ball to be rotated and picked up. The player continues the movement of the swim stroke by pulling the ball back up to the shoulder with the elbow and ball above the water surface. As the other arm pulls back in the front crawl stroke the ball is pushed forward from the throwing arm with contribution from the legs. As the legs perform a whip-like movement the elbow rapidly extends in a push-like movement and the trunk and shoulder may slightly rotate to add to ball speed (van der Wende & Keogh, 2005). The push shot is an accurate type of shot due to the linear path of the ball. However, once again, this type of shot is once again very specific to the situation within a game and it is essential a player performs this shot accurately as the ball speed is relatively lower in comparison to other types of shots which may increase the likelihood of the ball being blocked by opponents.

### *Rationale for thesis*

Much of the water polo shot research to date has aimed to determine the anthropometrical, physiological, and biomechanical factors associated with

superior performance of the water polo shot. This research has involved a variety of methods of analysis all conducted from a penalty situation. Penaty shots in water polo are performed from the 4m line with the goalkeepr in goal. In terms of specificity to competition only Davis and Blanksby (1977) used the goalkeeper in their data collection, although no record of accuracy or blocks was reported. All other research was conducted by shooting at an empty goal with no defenders present, in a situation similar to a penalty shot. Therefore, the effect of game specific task constraints on the water polo shot is not well understood. Consequently my thesis topic therefore aims to investigate the effect of the defender and goalkeeper as game specific task constraints on the technique, accuracy and speed of the water polo shot. The changes found by the presence of the defender and goalkeeper may have important implications for shooting practice in water polo.

# CHAPTER 3: METHODS

# Methods

## Participants

Ten male (mean $\pm$ *SD:* age 20.8 $\pm$ 2.3 years; height 188.4 $\pm$ 6.4 cm; mass 95.5 $\pm$ 11.6 kg) water polo athletes with a dominant right throwing arm and of national level participated in the current study. All participants were injury free at the time of testing and were all of field based positions. Each participant gave written informed consent prior to participating in this study. Ethical approval was obtained for all testing procedures from The Human Subject Ethics Committee, Auckland University of Technology.

## Design

The athletes were invited to perform forty shots under four different conditions (10 shots in each condition) from the 4m-penalty line in the centre of the water polo goal. The four conditions included:
1. No defender or goalkeeper;
2. One defender only;
3. Goalkeeper only;
4. One defender and the goalkeeper.

Within each condition a shot was performed every 20 seconds to minimise the effect of fatigue. The four conditions were randomised to reduce the order effect, with three minutes rest given between each condition.

An accuracy system was developed with the assistance of the New Zealand national coach and several senior national players. Prior to shooting the players were advised of the grid accuracy system and were advised that the task was to achieve maximum points by shooting into the high scoring areas. For the grid accuracy system the water polo goal (1.5m high by 3.0m wide) was divided into eighteen grids of fifty centimetres by fifty centimetres. Each grid was then assigned a score out of five relating to the likelihood of a shot scoring within a game situation. A score of one represented the lowest likelihood of scoring while a five represented the highest likelihood; a zero was assigned if the shot missed the goal (see Figure 3.1).

| | Left | | Centre | | Right | | |
|---|---|---|---|---|---|---|---|
| | 5 points | 3 points | 4 points | 4 points | 3 points | 5 points | Top |
| | 3 points | 2 points | 1 point | 1 point | 2 points | 3 points | Middle |
| | 5 points | 4 points | 1 point | 1 point | 4 points | 5 points | Bottom |
| | Far Left | Left | Centre Left | Centre Right | Right | Far Right | |

**Figure 3.1. Grid accuracy set up**

## Procedures

### *Testing sessions*

After the completion of a standardised warm-up that included swimming, egg beater and shooting drills, testing occurred. Each athlete completed their testing within one session.

### Participant instructions

The defender was instructed to be one metre in front of the shooter and to react in a typical defensive move that involved both arms up in the air to attempt to the block the shot. The defender was instructed not to make physical contact with the shooter but could move laterally along the one metre line. The goalkeeper was instructed to be situated along the goal line and attempt to block the shot as in a game situation.

*Apparatus*

A schematic representation for the testing sessions is shown in Figure 3.2. The shots at goal were filmed with four Sony DCR-TRV27E mini-digital cameras (Sony, Japan) operating at 50Hz with a shutter speed of 1/1000s. The cameras were placed perpendicular to the shot being performed, giving a sagittal view from the right side, a rear view and an overhead view. The sagittal camera was positioned 14m from the shooter, the rear camera was positioned 20m from the shooter and the overhead camera was positioned approximately 4m above the shooter. The rear and sagittal camera height was set to centre the participant at maximum height of their shot. Within the shooting area a vertical and horizontal (1m by 1m) calibration was taken in the direction of each camera. A Stalker-Pro radar gun (Stalker, USA) was used to collect the peak ball speed during the shots and was positioned approximately 20m directly behind the shooter according to manufacturer's specifications. Peak ball speed was measured in kilometres per hour, which was then converted to metres per second. The Stalker-Pro radar gun is accurate to $0.04\text{m.s}^{-1}$ (StalkerRadar, 2003).
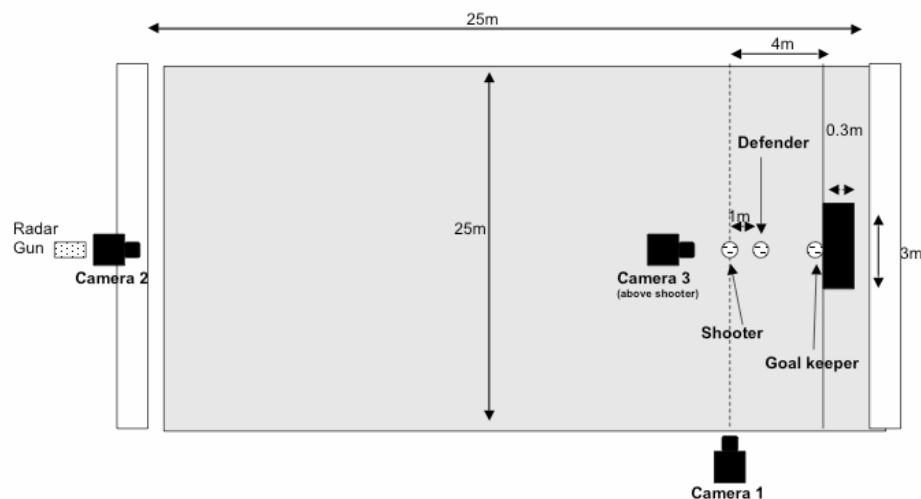


**Figure 3.2. A schematic of the set-up used during data collection**

*Data analysis*

Video footage collected from the overhead, rear and right side cameras was analysed frame-by-frame, from one frame prior to the ball being picked up off the water by the player until five frames after the ball was no longer in frame. The x and y co-ordinates of the athlete's joints were digitised using a kinematic analysis system (Ariel Performance Analysis System, U.S.A.). Consistent with previous research (Davis & Blanksby, 1977; Elliott & Armour, 1988; Feltner & Taylor, 1997; Whiting *et al.*, 1984), three points of the body were digitised from the right side camera: acromion process (C); olecranon process of elbow of the right arm (B); and the centre of the ball (A). Four points of the body were digitised from the overhead camera: acromion processes of the left (D) and right sides (C); olecranon process of the right elbow (B); and the centre of the ball (A) (see Figure 3.3). The data was smoothed using a low-pass digital filter with a cut off frequency of 8Hz.
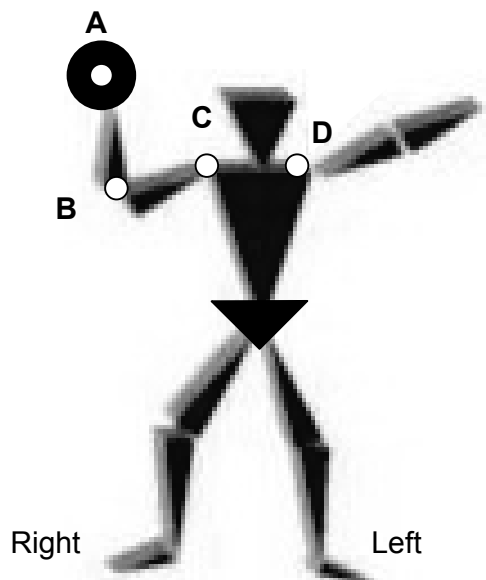


**Figure 3.3. Digitised body points**

*Key events of the shot*

Key events of the shot were as follows:

- Ball pick-up - the frame prior to the ball leaving the surface of the water (see Figure 3.4);
- Top of the Back swing - the frame prior to the ball moving forward towards release (see Figure 3.5);

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- Forward swing start – the frame immediately following the top of the back swing;

- Mid forward swing - The point at which the upper arm (from the side view) is directly in line with the body in horizontal abduction with the arm externally rotated (see Figure 3.6);

- Release - The frame where the ball has left the surface of the hand (see Figure 3.7).

### *Outcome measures*

Accuracy was determined for each shot. Accuracy was measured using three complementary methods. The simplest measure was whether the shot at goal was successful or unsuccessful. The grid accuracy system was used to determine the likelihood of scoring in a game situation. A maximum score for each of the ten shots was fifty. The grids were then further divided into left, right and centre sections of the goal to determine the placement of the shots within the goal across the different conditions. Each section contained six of the grids. Further division of the grids also occurred to determine which of the six columns and three rows of the goal the shots were placed. The grid was placed at the goal mouth (front of the goal), therefore, shots that went into the inner side of the net still passed through the grid at the front of the goal initially. The top and bottom right and left corners were also analysed for changes across the conditions. All accuracy measures were determined from the rear camera footage through visual analysis with the assistance of grid lines transposed over the video image of the goal. Ball speed at release was also recorded.

### *Linear measures*

Two linear measures were determined for all the shots. Forward swing distance was established from the sagittal camera. This ball displacement distance was measured from the top of back swing to release. Height at release was obtained from the sagittal camera and was equal to the height of the ball from the water surface at ball pick up to that at release.

**Figure 3.4. Ball pick-up**
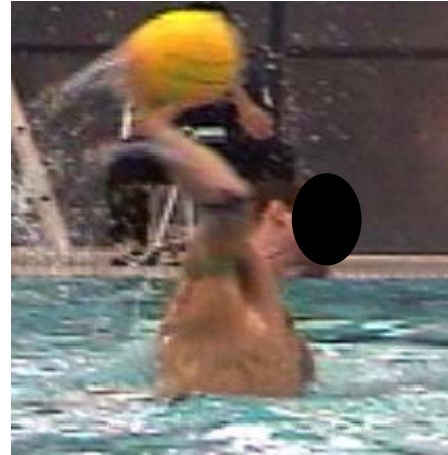


**Figure 3.6. Middle of the Forward swing**



**Figure 3.5. Top of Back swing**



**Figure 3.7. Release**

### Angles at release

Shoulder angle in relation to target at release was determined from the above camera using the shoulder markers (see Figure 3.8).
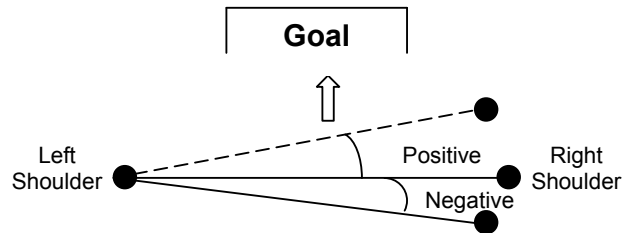


**Figure 3.8. Shoulder angle at release**

Lateral trunk angle at release was determined from the rear camera taken at release of the ball relative to vertical (see Figure 3.9)



**Figure 3.9. Lateral trunk angle at release**

### Temporal measures

Temporal measures were determined for the following phases:

- Shot Time - from ball pick up to ball release;
- Pick-up to Top of Back swing - from pick up to top of back swing;
- Forward swing Start to Release - from the start of the forward swing to ball release;

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- Forward swing Start to Midway - from start of the forward swing to midway
- Forward swing Midway to Release - from forward swing midway to release

Each of these sub phases was expressed in absolute (seconds) and relative (percent of total shot time) terms.

Inter-trial reliability was determined for the digitised data and the discrete measures. Ten trials were selected and re-analysed to test reliability. The intra-class coefficient, Pearson's correlation coefficient ($r^2$) and typical error as a coefficient of variance (%) of all the ten trials of selected variables were calculated (Hopkins, 2000). Strong relationships were found between the selected variables for the intra-class coefficient (0.926 - 1.00), Pearson's correlation coefficient (0.892 – 1.00) and typical error as a coefficient of variance (1.1 – 20.5%), indicating these measures were reliable.

**Statistical Analysis**

Means and standard deviations were calculated for the dependent variables across all subjects, conditions and trials. A repeated measures ANOVA (Group (1) x condition (4)) was used to determine the effect of the different task constraints on the water shot for the group and individual analysis. The effect between conditions was determined through post-hoc analysis (Tukey test). Effect sizes have been suggested as an alternative to inferential statistics in biomechanics and motor control research because they provide an estimate of the meaningful differences between variables in an experiment (Mullineaux *et al.*, 2001). Cohen's effect sizes were used to determine the magnitude of the differences between the conditions. Small (0.2 - 0.5), medium (0.5 – 0.8), large (>0.8) effects were used for analysis (Cohen, 1988). The likelihood of a type one error in statistical analysis can be determined to find how many results of significance will be returned by chance alone. The number of possible type one errors would be 2 out of 40 for individual analysis and 10 out of 200 for group analysis ($p < 0.05$). All statistical analyses were carried out using SAS statistical software (SAS Institute Inc., Cary, NC, USA) at a significance of $p < 0.05$.

# CHAPTER 4: RESULTS

# Group Results

Condition one (no defender or goalkeeper present) was used as the 'control' condition and was compared with all other conditions to determine the effect of the goalkeeper and defender on the outcome as well as the spatial and temporal characteristics of the water polo shot.

## Part A: Outcome measures

### Ball speed

The mean ball speed across all conditions was $18.2 \pm 1.4$ m.s$^{-1}$. The mean ball speed for each of the four conditions can be seen in Figure 4.1.
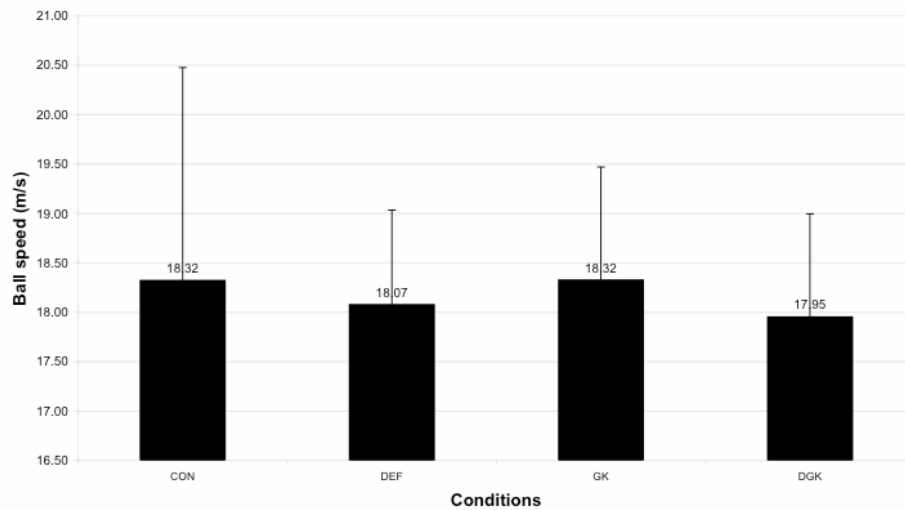


**Figure 4.1. Mean ball speed for each condition**

<u>Key</u>: **CON** - control condition, no defender or goalkeeper (1); **DEF** – defender only condition (2);

    **GK** – goalkeeper only condition (3); **DGK** – defender and goalkeeper condition (4).

    Note: All data is in means ± SD.

There were no significant effects between any of the conditions for ball speed. However, there was a trend ($p < 0.056$) supported by small effect sizes towards a decrease in ball speed between the control condition and the defender and

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goalkeeper condition ($F_{(3,27)}$=2.01, p=0.0561, ES=0.452); and the goalkeeper only and defender and goalkeeper condition ($F_{(3,27)}$=2.01, p=0.0597, ES=0.477).

*Accuracy*

Overall 400 shots were performed, with 307 (76.8%) of these shots successful. The number of successful shots achieved in each condition is shown in Figure 4.2.
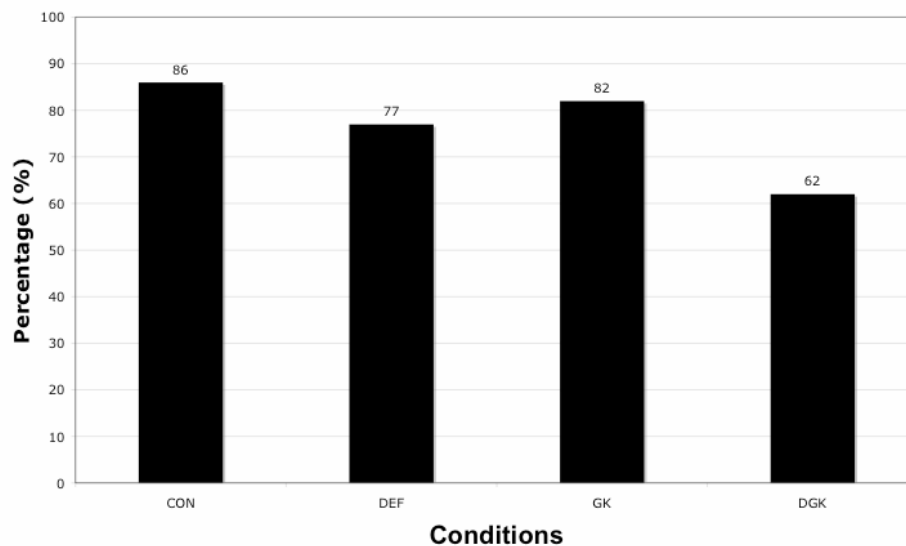


**Figure 4.2. Percentage of successful shots for all conditions**
<u>Key</u>: **CON** - control condition, no defender or goalkeeper (1); **DEF** – defender only condition (2);
    **GK** – goalkeeper only condition (3); **DGK** – defender and goalkeeper condition (4).

There was a significant difference in the number of shots scored between the control condition and the defender and goalkeeper condition ($F_{(3,27)}$=5.95, p=0.0005, ES=1.37); the defender only and the defender and goalkeeper condition ($F_{(3,27)}$=5.95, p=0.0096, ES=0.707); and the goalkeeper only and defender and goalkeeper conditions ($F_{(3,27)}$=5.95, p=0.0041, ES=1.284).

*Placement of Shots*

Placement of the successful shots was determined using the grid accuracy set up over the goal. The goal was broken up into 18 grids. These grids were then

divided into left, centre and right which each contained 6 grids from two vertical and 3 horizontal columns. The highest proportions of successful shots across all conditions were placed in the far right hand side (39.5%) and in the middle third of the goal (31.0%).

Shots performed in the control condition were primarily shot into the far right hand side (59%) and in the middle third (32%) of the goal. Shots that were performed in the defender only condition were shot equally into the far left (39%) and right (39%) in the middle third (42%) of the goal. The goalkeeper only condition shots were primarily shot into the far right hand side (39%) in the middle third (31%) of the goal. The defender and goalkeeper condition shots were mainly shot into the far left (34%) in the bottom third (27%) of the goal. Figure 4.3 shows the placement of successful shots by columns in percentages from each condition. Figure 4.4 shows the placement of successful shots by rows in percentages from each condition.
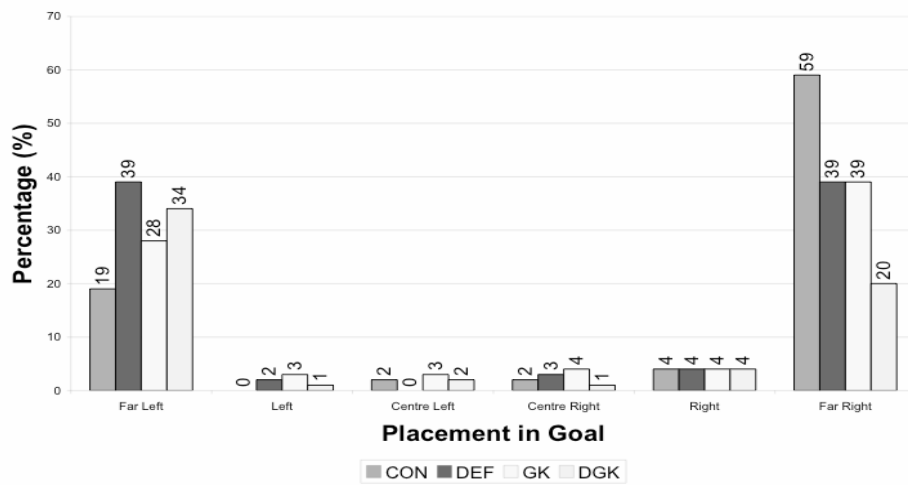
**Figure 4.3. Placement of all conditions successful shots (%) vertically in goal**

<u>Key</u>: **CON** - control condition, no defender or goalkeeper (1); **DEF** – defender only condition (2); **GK** – goalkeeper only condition (3); **DGK** – defender and goalkeeper condition (4).



**Figure 4.4. Placement of all conditions successful shots (%) horizontally in goal**

<u>Key</u>: **CON** - control condition, no defender or goalkeeper (1); **DEF** – defender only condition (2); **GK** – goalkeeper only condition (3); **DGK** – defender and goalkeeper condition (4).

All the condition comparisons resulted in a decrease or movement of proportionately more goals shot towards the left hand side of the goal (see Table 4.1). However there was one exception to this result in the defender only and goalkeeper only conditions comparison where there was a trend towards a greater proportion of shots towards the right hand side of the goal ($F_{(3,27)}$=12.19, p=0.1364, ES=0.547).

**Table 4.1 Significant effects between conditions for placement of shots**

|  | Condition 1 & 2 | Condition 1 & 3 | Condition 1 & 4 | Condition 2 & 3 | Condition 2 & 4 | Condition 3 & 4 |
|---|---|---|---|---|---|---|
| **p value** | 0.0005** | 0.0208* | <.0001** | 0.1364 | 0.0764 | 0.0022* |
| **Effect size** | 1.230$^{ß}$ | 0.936$^{ß}$ | 1.768 | 0.547** | 0.529** | 1.181$^{ß}$ |
| **Direction of Change** | ↓ | ↓ | ↓ | ↑ | ↓ | ↓ |

Key: * p-value <0.05 or small ES <0.2; ** p-value <0.001 or medium ES <0.5; $^{ß}$ large ES <0.8

**Condition 1** - control condition, no defender or goalkeeper; **Condition 2** – defender only;

**Condition 3** – goalkeeper only; **Condition 4** – defender and goalkeeper.

The top and bottom corners are the most difficult to accurately shoot to and for the goalkeeper to block within a game situation. The difference in percentage of shots into these corners was examined between conditions. Table 4.2 shows the changes across the conditions between left and right top and bottom corners.

**Table 4.2 Percentage change between conditions of the successful shots in the corners of the goal across all conditions**

|  | Condition 1 & 2 | Condition 1 & 3 | Condition 1 & 4 | Condition 2 & 3 | Condition 2 & 4 | Condition 3 & 4 |
|---|---|---|---|---|---|---|
| **Top Left** | ↑ 2% | ↑ 2% | ↑ 2% | = | = | = |
| **Bottom Left** | ↑ 8% | ↑ 8% | ↑ 11% | = | ↑ 3% | ↑ 3% |
| **Top Right** | ↓ 11% | ↓ 10% | ↓ 12% | ↑ 1% | ↓ 1% | ↓ 2% |
| **Bottom Right** | ↓ 6% | ↓ 10% | ↓ 10% | ↓ 4% | ↓ 4% | = |

Key: **Condition 1** - control condition, no defender or goalkeeper; **Condition 2** – defender only;

**Condition 3** – goalkeeper only; **Condition 4** – defender and goalkeeper.

### *Score Achieved*

Each shot performed was given a score out of five according to its placement in the goal according to the grid accuracy scoring system developed. The average score out of 50 (highest score achievable) from each condition can be seen in Figure 4.5.

A significant decrease in the score achieved across the shots performed was found between the control condition and the defender and goalkeeper condition ($F_{(3,27)}$=4.27, p=0.0019, ES=1.313); defender only and defender and goalkeeper conditions ($F_{(3,27)}$=4.27, p=0.0414, ES=0.613); and the goalkeeper only and defender and goalkeeper conditions ($F_{(3,27)}$=4.27, p=0.0155, ES=1.066).
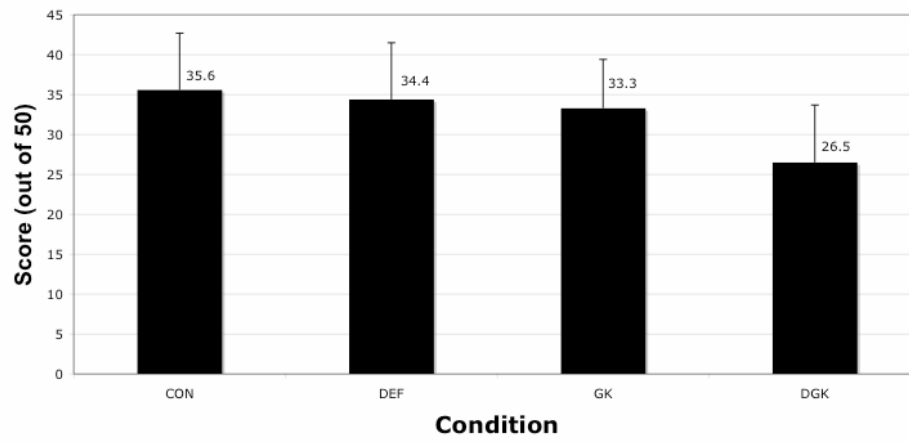


**Figure 4.5. Mean score of successful shots performed for all conditions**
<u>Key</u>: **CON** - control condition, no defender or goalkeeper (1); **DEF** – defender only condition (2);

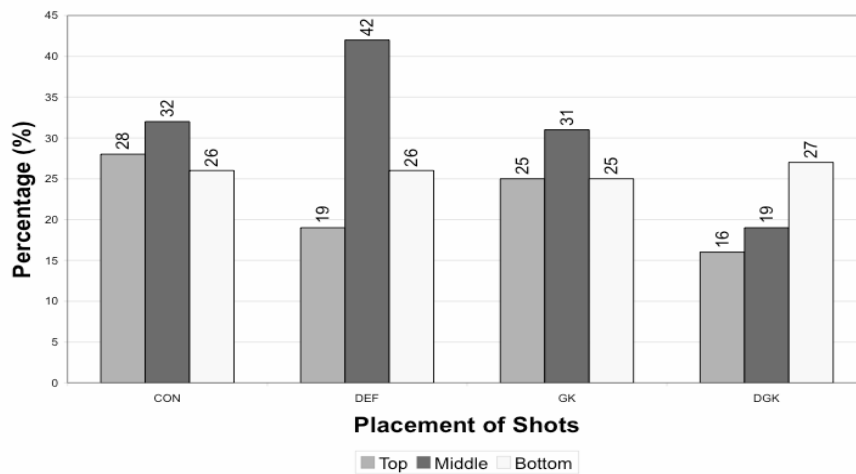**GK** – goalkeeper only condition (3); **DGK** – defender and goalkeeper condition (4).

Note: All data is in means ± SD.


## Part B: Linear measures


### *Forward Swing Distance*

The forward swing distance was examined between all combinations of conditions to determine the effect of the defender and goalkeeper on the distance the ball was moved from the top of the back swing to ball release (see Table 4.3).

The defender and goalkeeper condition was significantly different from the defender only condition with an increase in forward swing distance ($F_{(3,27)}$=2.02,

p=0.0207, ES=0.206). All other condition comparisons resulted in no significant differences.

### Height at Release

The height at release between all combinations of conditions was examined to determine the effect of the defender and goalkeeper on the height achieved at ball release (see Table 4.3).

There were no significant differences in height at release between the conditions.

**Table 4.3 Linear variables means $\pm$ SD for all conditions**

|  | CON | DEF | GK | DGK |
|---|---|---|---|---|
| Forward Swing distance (cm) | 117.7 $\pm$ 34.9 | 113.9 $\pm$ 40.9 | 117.9 $\pm$ 33.1 | 122.3 $\pm$ 37.9 |
| Height at ball release (cm) | 103.1 $\pm$ 21.0 | 101.8 $\pm$ 19.8 | 101.5 $\pm$ 16.2 | 101.9 $\pm$ 21.9 |

Key: **CON** - control condition, no defender or goalkeeper (1); **DEF** – defender only condition (2); **GK** – goalkeeper only condition (3); **DGK** – defender and goalkeeper condition (4).

### Part C: Angular measures

### Lateral Trunk angle at ball release

Lateral trunk angle at ball release was examined to determine the effect of the defender and goalkeeper over the four conditions (see Table 4.4).

When the defender only condition was compared with the goalkeeper only condition there was a significant decrease in the lateral trunk angle at release ($F_{(3,27)}$=3.98, p=0.0096, ES=0.417). This result was reversed when the goalkeeper only condition was compared with the defender and goalkeeper condition and there was a significantly larger lateral trunk angle at ball release ($F_{(3,27)}$=3.98, p=0.007, ES=0.524).

### Shoulder angle in relation to target at ball release

Shoulder angle in relation to target at ball release was examined over the four conditions to determine the effect of the defender and goalkeeper (see Table 4.4).

There were no significant differences in the shoulder angle at release between the four conditions.

**Table 4.4 Angles at ball release variables means ± SD for all conditions**

|  | CON | DEF | GK | DGK |
|---|---|---|---|---|
| Lateral trunk angle (°) | 29.5 ± 11.6 | 32.8 ± 23.1 | 27.5 ± 13.3 | 33.1 ± 15.6 |
| Shoulder angle (°) | 11.8 ± 26.4 | 7.9 ± 29.8 | 9.3 ± 33.1 | 11.4 ± 33.2 |

Key: **CON** - control condition, no defender or goalkeeper (1); **DEF** – defender only condition (2); **GK** – goalkeeper only condition (3); **DGK** – defender and goalkeeper condition (4).


## Part D: Temporal measures

### *Total Shot Time*

The total shot time from ball pick up to the release of the ball was examined for differences between the four conditions (see Figure 4.6).

There were significant decreases between the control condition and the defender only condition ($F_{(3,27)}$=4.10, p=0.024, ES=0.230); the control condition and the goalkeeper only condition ($F_{(3,27)}$=4.10, p=0.0028, ES=0.583); and the control condition and the defender and goalkeeper condition ($F_{(3,27)}$=4.10, p=0.0163, ES=0.433).
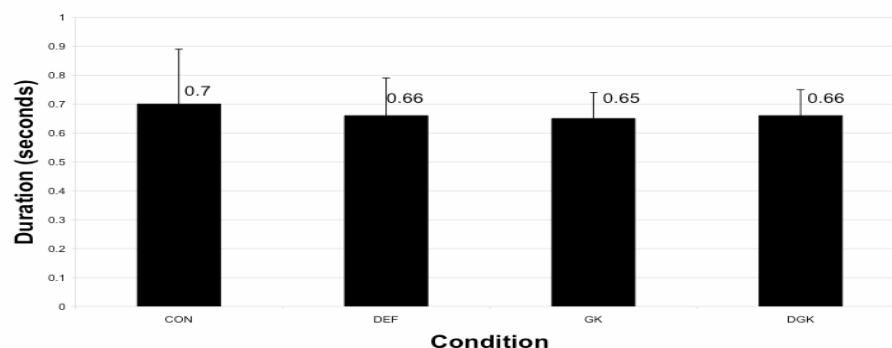


**Figure 4.6. Total shot time (s) for all conditions**
Key: **CON** - control condition, no defender or goalkeeper (1); **DEF** – defender only condition (2); **GK** – goalkeeper only condition (3); **DGK** – defender and goalkeeper condition (4).

Note: All data is in means ± SD.

### Pick up to top of back swing

The duration and proportion of total shot time was examined for the initial phase of the shot from ball pick up to top of the back swing to determine the effect of the defender and goalkeeper (see Table 4.5).

There was a significant decrease in phase duration between the control condition and the defender only condition ($F_{(3,27)}$=6.47, p=0.0026, ES=0.439); control condition and goalkeeper only condition ($F_{(3,27)}$=6.47, p=0.0037, ES=0.579); and the control condition and the defender and goalkeeper condition ($F_{(3,27)}$=6.47, p=0.0004, ES=0.697). There was a significant decrease in proportion of shot duration in this phase between the control condition and the defender only condition ($F_{(3,27)}$=11.76, p=0.0001, ES=0.445); the control condition and the goalkeeper only condition ($F_{(3,27)}$=11.76, p=0.0093, ES=0.569); the control condition and the defender and goalkeeper condition ($F_{(3,27)}$=11.76, p=>.0001, ES=961); and the goalkeeper only and the defender and goalkeeper condition ($F_{(3,27)}$=11.76, p=0.0099, ES=0.417).

**Table 4.5 Ball pick up to top of back swing means ± SD for all conditions**

|  | CON | DEF | GK | DGK |
|---|---|---|---|---|
| Phase duration (s) | 0.4 ± 0.2 | 0.3 ± 0.1 | 0.3 ± 0.1 | 0.3 ± 0.1 |
| Proportion of total shot (%) | 54.4 ± 6.9 | 46.8 ± 11.6 | 48.5 ± 8.2 | 45.6 ± 10.9 |

Key: **CON** - control condition, no defender or goalkeeper (1); **DEF** – defender only condition (2); **GK** – goalkeeper only condition (3); **DGK** – defender and goalkeeper condition (4).

### Forward swing start to midway through forward swing

The duration and percentage of total shot time was examined for the phase from forward swing start to midway through the forward swing to determine the differences between the four conditions (see Table 4.6).

There was a significant decrease in duration between the defender only condition and the defender and goalkeeper condition ($F_{(3,27)}$=1.85, p=0.0426, ES=0.279) and percentage of shot duration between the goalkeeper only and the defender and goalkeeper condition ($F_{(3,27)}$=3.37, p=0.0042, ES=0.410).

**Table 4.6 Forward swing start to midway means ± SD for all conditions**

|  | CON | DEF | GK | DGK |
|---|---|---|---|---|
| Phase duration (s) | 0.13 ± 0.03 | 0.12 ± 0.04 | 0.13 ± 0.04 | 0.13 ± 0.03 |
| Proportion of total shot (%) | 18.2 ± 5.0 | 18.2 ± 5.6 | 19.8 ± 6.5 | 17.4 ± 7.2 |

Key: **CON** - control condition, no defender or goalkeeper (1); **DEF** – defender only condition (2);
**GK** – goalkeeper only condition (3); **DGK** – defender and goalkeeper condition (4).

### *Forward swing start to release*

The duration and percentage of total shot time was examined for the entire forward swing phase start to release to determine the differences between the four conditions (see Table 4.7).

There was a significant increase in duration between the defender only and the defender and goalkeeper condition ($F_{(3,27)}$=1.64, p=0.0483, ES=0.229).

**Table 4.7 Forward swing start to release means ± SD for all conditions**

|  | CON | DEF | GK | DGK |
|---|---|---|---|---|
| Phase duration (s) | 0.19 ± 0.03 | 0.18 ± 0.03 | 0.19 ± 0.04 | 0.19 ± 0.03 |
| Proportion of total shot (%) | 28.0 ± 5.5 | 28.7 ± 6.5 | 29.5 ± 6.3 | 28.6 ± 3.5 |

Key: **CON** - control condition, no defender or goalkeeper (1); **DEF** – defender only condition (2);
**GK** – goalkeeper only condition (3); **DGK** – defender and goalkeeper condition (4).

### *Forward swing midway to release*

The duration and percentage of total shot time was examined for the last phase of the forward swing phase from midway to release to determine the effect of the defender and goalkeeper (see Table 4.8). There was no significant difference in duration or percentage of total shot for this phase across any of the conditions.

**Table 4.8 Forward swing midway to release means ± SD for all conditions**

|  | CON | DEF | GK | DGK |
|---|---|---|---|---|
| Phase duration (s) | 0.07 ± 0.02 | 0.07 ± 0.02 | 0.06 ± 0.02 | 0.07 ± 0.02 |
| Proportion of total shot (%) | 9.8 ± 3.8 | 10.5 ± 4.1 | 9.8 ± 4.0 | 10.3 ± 3.5 |

Key: **CON** - control condition, no defender or goalkeeper (1); **DEF** – defender only condition (2);
**GK** – goalkeeper only condition (3); **DGK** – defender and goalkeeper condition (4).

# CHAPTER 5: DISCUSSION

The presence of the defender and/or goalkeeper resulted in a number of significant changes to the accuracy, placement in goal, ball speed and shooting technique of the water polo shot. Specifically, the presence of the defender caused a significant increase in lateral trunk angle at ball release; a decrease in the total shot duration, and selected sub-phases of the shot (i.e. pick-up to top of the back swing) and significantly altered the placement of the shots in the goal. The presence of the goalkeeper significantly altered the placement of the shots in the goal and decreased the duration of the shot and selected sub-phases of the shot (i.e. pick-up to top of the back swing). When both the goalkeeper and defender were present the ball speed and the number of successful shots decreased, with changes in shooting placement from the right to the left hand side of the goal also observed. Duration of sub-phases of the shot decreased when both the defender and goalkeeper were present: the pick-up to top of back swing phase; forward swing start to mid-swing phase; and forward swing start to release phase. Forward swing distance and lateral trunk angle at release increased in the presence of the defender and goalkeeper. The following sections discuss the effect of the defender only, goalkeeper only and the combination of the defender and goalkeeper on the changes in the water polo shot. Theoretical, practical and future research recommendations are discussed in relation to the findings of the study.

## Control Condition

The condition that included no defender or goalkeeper was termed the "control condition". This condition was comparable to virtually the entire water polo shooting literature. By comparing the control condition to the other three, the effect of the defender and/or goalkeeper on the water polo shot could be examined.

### *Shot Direction and Success Rate*

There was a high rate of success in the control condition (86%). Shots were predominantly aimed into the middle grid (32%) of the far right hand side of the goal (59%), with fewer shots in the far left hand side of the goal (19%). Previous research by Clarys and colleagues (1992) found a success rate of 100% when participants shot from the 4m-penalty line. The reduced success rate in the

current study may relate to the aim of the task which was to score in the high scoring areas of the goal according to the grid system developed rather than simply shooting down the middle. The participants were also more likely to shoot into the far right hand side of the goal, as they were all dominant right-hand shooters. Therefore, shooting to the right hand side was simpler and likely to be more accurate as the shooter did not need to increase their lateral trunk flexion or arm movement, which would be required to shoot the ball to the left hand side of the goal.

### Ball Speed

A mean ball speed of $18.3 \pm 1.1$ m.s$^{-1}$ for the control condition was within the range of 15-20 m.s$^{-1}$, reported in previous studies for athletes of club or national level (Davis & Blanksby, 1977; Elliott & Armour, 1988; Feltner & Taylor, 1997; Whiting *et al.*, 1984).

### Forward Swing Distance

Forward swing distance was found to be $117.7 \pm 34.9$ cm in the control condition. Although no other studies have appeared to assess forward swing distance, Davis and Blanksby (1977) did record forward head displacement during the shot. When comparing national and club level players Davis and Blanksby (1977) found the national level players showed a greater amount of forward movement than the club level players.

### Height at Release

Height at release was found to be $103.1 \pm 21.0$ cm within the control condition. No direct comparison of these results can be made as this study used height at release whereas other studies have used maximal height.

### Lateral Trunk Angle at Release

Lateral trunk angle at release was $29.5 \pm 11.6°$ in the control condition. This was slightly lower than that found by Davis and Blanksby (1977). They found higher lateral movement angles for national players (45°) compared with club players (34°) (Davis & Blanksby, 1977). This lower amount of movement found in this study may be due to the specific task constraint of shooting within a grid scoring system. It is worth noting the large amount of relative variation for

lateral trunk angle within this condition. The increased variation around the mean score in the lateral trunk movement may also be suggestive of expert behaviour and utilising functional variability of the movement to perform a successful shot (Button *et al.*, 2003).

### *Temporal Measures*

Temporal durations and phases of the shot in the control condition were similar to those found in a previous study (Ball, 1996). The total shot duration for the control condition was $0.7 \pm 0.2$ s, which was similar to the 0.6 s reported by Ball (1996). The proportions of the sub-phases illustrate, as expected, that the initial phase from ball pick-up to top of the back swing was the longest duration and proportion of total shot time (54%) and that the forward swing phase was of a much lower duration and proportion of total shot time (28%).

## Effect of the Defender

The defender only condition caused significant changes to the ball placement in the goal, decreases in selected sub-phases of the shot (i.e. total shot duration and ball pick-up to top of the back swing) and an increase in lateral trunk angle at release.

### *Shot Placement and Success Rate*

When the defender was present, the number of successful shots decreased by 9% in comparison to the control condition (86% to 77%), which was statistically significant. 2.5% of shots were blocked by the defender in this condition indicating that 21.5% of the shots missed the goal.

The presence of the defender significantly altered the placement of the shots in goal as predicted. The direction of shots significantly changed from the control condition. The placement changed from the right to the left hand side of the goal. Shots were also predominantly placed in the middle third of the goal. The main difficulty for the shooters in this condition appeared be getting the ball past the protected area where the defender was present one metre in front on them.

Hence, the aim of the shooter was to get the ball around the defender in order to place the shot in an unprotected area of the goal.

### *Lateral Trunk Angle at Ball Release*

A significant increase of 3.3º in the lateral trunk angle at ball release was observed. This finding was in line with the predictions made that an increase in lateral flexion would allow the shooter to shoot around the defender and into the goal. Increased lateral trunk flexion also contributes to ball speed by increasing the lever arm as well as increasing the height of release which may also contribute to successfully shooting the ball past the defender (Alexander & Honish, 2005). Due to a lack of research into changes in lateral movement in the presence of a defender, no comparisons can be made. These changes may be due to individual preference or defender bias (defender may encourage shots to a particular part of the goal through defensive movements). However, no measures of preference or bias were obtained in the current study.

### *Temporal Measures*

The duration of the shot phases was expected to decrease due to the presence of the defender. This decrease in phase duration was hypothesised to be accompanied by an increase in ball speed. While ball speed did not increase as a result of the defender being present, there was a significant decrease in the total shot duration from 0.70 s for the control condition to 0.66 s for the defender only condition. There was also a significant decrease in the phase from ball pick-up to top of the back swing from 54% in the control condition to 47% in the defender only condition.

The initial phase from ball pick-up to the top of the back swing appeared to contribute to the overall decrease in total shot duration. Shorter initial phase duration may have been employed by the participants because it could minimise the amount of reaction time available to the defender to attempt to block the shot. The shooter therefore minimises the information and time available to the defender to form a functional movement in an attempt to block the shot.

# Effect of the Goalkeeper

Individually the presence of the goalkeeper caused significant changes to the ball placement in the goal and decreased the duration of sub-selected phases of the shot (i.e. shot duration and ball pick-up to top of the back swing).

## *Shot Placement and Success Rate*

The success rate of the shots in the goalkeeper only condition significantly decreased by 4% in comparison to the control condition. As predicted the presence of the goalkeeper altered the placement of the shots in goal causing a greater amount of shots to be placed in the left hand side of the goal (28%) in comparison to the control condition (19%). The shots in this condition were predominantly placed in the middle grid (31%) of the far right hand side (39%). Such placement is different to the control condition where the shots were predominantly placed in the middle grid (32%) of the far right hand side (59%).

The change in the participants' placements of shots in the middle grid of the left hand side of the goal may be due to the goalkeeper's presence. A goalkeeper will traditionally boost up with arms outstretched to block as much of the goal as possible with their body. When their arms are outstretched, the middle third of the goal is well protected. The fact that the participants in this study placed their shots with a high degree of success in the middle grid of the far left hand side of the goal in the presence of the goalkeeper may indicate that the participants were well-practised at shooting in the presence of the goalkeeper. Hence, the participants may have been able to alter their movements in order to mislead the goalkeeper into not blocking this particular area of the goal and were, therefore, able to maintain a high level of success in their shots.

## *Temporal Measures*

There was a significant decrease in total shot duration (Condition 1: $0.7 \pm 0.2$ s; Condition 3: $0.65 \pm 0.1$ s), primarily as a result of a decrease from 54% in the control condition to 48% in this condition within the initial phase from ball pick-up to top of the back swing. The phase durations were predicted to decrease when the goalkeeper was present presumably as a result of increased ball speed. However, ball speed did not increase but as reported above, there was

a decrease in the duration of the initial phase and the total shot time. As discussed in the previous section (Effect of Defender), this decrease may be due to the shooter attempting to minimise the reaction time and information available to the opposition players, thus reducing the opponents (in this case goalkeeper's) ability to form a functional movement in an attempt to block the shot.

## Effect of the Defender and Goalkeeper

The presence of both the defender and goalkeeper in the shooting environment caused significant changes to the majority of the variables measured. There was a moderate effect on ball speed, a significant decrease in shot accuracy and altered placement of the shots. Forward swing distance and selected shot phases (i.e. total shot time, pick-up to top of the back swing, forward swing start to midway and forward swing start to release) decreased while lateral trunk angle at release increased.

### *Shot Placement and Success Rate*
The presence of the defender and goalkeeper caused a drop in the number of successful shots from 86% to 62%. However, it should be noted that this result may have been due to the instructions given to shoot with the aim of achieving the highest possible points according the grid system applied to the goal, as well as the presence of the defender and/or goalkeeper. The higher scoring areas were on the outer areas of the goal, which may have made achieving a successful shot more difficult. Nevertheless, the protocols used in this study were more specific to game situations than other studies, although the shooting environment was still not completely competition specific. The environment was not completely competition specific due to the absent levels of organization amongst the individuals and sub-groups as occurs within a game, and as such may not have truly reflected that which occurs in game situations between the players (Chow *et al.*, 2006).

In addition, the placement of shots differed significantly between the control and combined defender and goalkeeper conditions. More shots were placed in the left hand side of the goal when the defender and goalkeeper were present in

comparison to the control condition (19% versus 34%). The placements of the shots was also affected by the presence of both the defender and goalkeeper. In the control condition, or when the defender or goalkeeper was present separately, the shots were placed primarily in the middle grid of the far left of the goal. However, when the goalkeeper and defender were both present, the shots were mostly placed in the bottom grid of the far left of the goal. Shooting into the bottom grid of the far left of the goal when the defender and goalkeeper were present may be due to the shooter reacting to where the goalkeeper and defender are blocking. If the defender is blocking with both arms up, the goalkeeper will generally boost up with arms extended straight up and to the side from the shoulders. Therefore, the top and bottom areas of the goal are protected and the available shooting avenue becomes the bottom section of the goal.

### *Ball Speed*

It was predicted that ball speed would increase in the presence of opposition players, requiring the shooter to shoot the ball faster past the opponents in order to minimise their time available to block the shot. This hypothesis was not supported by the results. There was actually a non-significant trend, supported by a moderate effect size, that indicated the ball speed was less when the defender and goalkeeper were present compared to the control condition. This effect on ball speed with the addition of the defender and goalkeeper has not been examined by previous studies. Although a goalkeeper was included in Davis and Blanksby (1977), the effect of the goalkeeper's presence on the shooting speed was not examined.

The ball speed of a shot at goal is an important predictor of whether or not the shot is likely to be successful, as a slower shot will allow extra time for the defender and/or goalkeeper to block the shot. However, a fast shot is not always suitable for certain situations and often accuracy is more important. Players may need to be able to modify the ball speed according to the situation and whether the defender and/or goalkeeper are present. In essence, this ability is the speed-accuracy trade-off or Fitt's law (Fitts & Posner, 1967). The speed-accuracy trade-off must be determined by the player in order to identify when speed is needed and when it is more appropriate to select an accurate

shot (Magill, 2003). This ability to determine when to use either speed or accuracy develops predominantly in practice or through game experience.

*Forward Swing Distance*

A significant increase of 8.4 cm in the forward swing distance was found when the defender only condition was compared with the goalkeeper and defender condition. Forward swing distance was predicted to increase in the presence of the defender and goalkeeper because this greater distance would increase the time of force application and may result in an increase in ball speed. An increased forward swing distance could also allow the shooter more time to alter the trajectory of the ball in order to further minimise the possibility of it being blocked by the defender or goalkeeper. A longer forward swing distance, however, brings the shooter closer to the defender, possibly causing a greater reduction in the available direction in which the shots can go, thus restricting the potential movement possibilities.

*Height at Ball Release*

There were no significant differences in the height of release in the presence of the goalkeeper and defender. Although height at ball release was hypothesised to increase as a result of the presence of the defender and goalkeeper, an increased height out of the water allows the shooter's body to be above the surface of the water, thus allowing better trunk rotation as the resistance from the water is minimised.  This would likely result in increased ball speed (Alexander & Honish, 2005). In additional, the greater the height out of the water, there is less possibility of the defender blocking the shot (Feltner & Taylor, 1997).

As previously mentioned, it has been suggested that an optimal rather than maximal height may be beneficial for shot performance (Davis & Blanksby, 1977; Elliott & Armour, 1988). In this study the mean height of release was relatively similar across all the conditions, further suggesting that players find an optimal height and thus the height of release remains steady across the conditions. It is also possible that the lack of significance for this variable across the conditions may reflect reduced intra-test reliability of this measure. The reliability results of this variable showed a strong relationship between the test

and retest, further suggesting that height of release is reasonably stable in all of the conditions tested (see Appendix 6). This consistency in the height at ball release could suggest that players set this height for their shot regardless of the opposition present and may be able to alter other aspects of their coordination in order to adapt to the opposition present.

### *Lateral Trunk Angle at Ball Release*

Compared to the control condition, the lateral trunk angle at release increased significantly by 3.5º when the defender and goalkeeper were present. The lateral trunk angle at ball release was predicted to increase when the goalkeeper and defender were present within the shooting environment. However, this variable did demonstrate a large amount of variability across the conditions, with the results for this condition being 33.1 ± 15.6º. As the reliability of this variable was very strong ($R^2$ = 0.96; ICC = 0.96; CV = 5.1%), it would appear that the high levels of relative variability in lateral trunk angle may be due to the participants demonstrating functional variability across the different trials of each condition.

The noted increase in lateral trunk angle may be due to the participants' desire to minimise loss of ball speed by increasing the lever arm and release height. In addition, their shots may have been altered in this way in order to decrease the chance of the opposition blocking the shot (Alexander & Honish, 2005). Increased lateral trunk movement when shooting may have also allowed the players a greater range of possibilities in terms of which direction the shot would be directed, something of great advantage when shooting around defenders and goalkeepers.

### *Temporal Measures*

The duration and phases of the shot were expected to decrease as ball speed increased in response to the presence of the defender and goalkeeper. Although ball speed did not increase, the total shot duration decreased significantly when the defender and goalkeeper were present from 0.7 ± 0.2 s in the control condition to 0.66 ± 0.1 s in this condition. The majority of the decrease in shot time occurred in the initial phase from ball pick-up to top of the back swing.

The alterations in the phase durations seen in the combined defender and goalkeeper condition suggest that the shooter is attempting to minimise the reaction time available to the opponents to block the shot, especially in the case of the initial pick-up phase. The forward swing is potentially the most important phase of the shot for the goalkeeper because it provides information on the likely speed and trajectory of the shot. Therefore, this decrease in duration of the initial phase from ball pick-up to top of the back swing and forward swing phase would have reduced the amount of time for the defender and goalkeeper to react and block the shot. Consequently the shooter is diminishing the amount of information available to the opponent(s) in an attempt to decrease their ability to form functional movements and so the shot is less likely to be blocked.

## Theoretical Implications

The findings of the current study indicated that the presence of a defender and/or a goalkeeper significantly altered the outcome and manner in which national level players performed the water polo shot. The presence of the defender caused a significant decrease in the lateral trunk movement, altered the placement of the shots in the goal and decreased the total shot duration and selected sub-phases of the shot (i.e. ball pick-up to top of the back swing). In the presence of the goalkeeper only, the placement of the shots were significantly altered and a significant decrease in the total shot duration and selected sub-phases was found (i.e. ball pick-up to top of the back swing). The presence of both the defender and goalkeeper caused a number of significant differences, with these being greater in number and magnitude than that of the defender or goalkeeper alone. There was a moderate effect resulting in a decrease in ball speed when the defender and goalkeeper were present. Additionally, there was a significant decrease in the number of successful shots, and an alteration in the placement of the shots was also found in the presence of the defender and goalkeeper. Forward swing distance and selected sub-phases of the shot (i.e. total shot time, pick-up to top of the back swing, forward swing start to midway and forward swing start to release) were also significantly decreased.

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These changes in the outcome and technique of the water polo shot are consistent with Newell's (1986) constraint-led approach to motor control. This approach postulates that any alteration to the constraints under which a task is performed leads to significant changes in the coordination solution and the outcome of the task. Similar results have been observed in other studies, demonstrating the link between the adaptations in the movement pattern to constraints present within the environment (Guerin & Kunkle, 2004; Newell & McDonald, 1994).

Although the accuracy and direction of the water polo shots was significantly altered as a consequence to the presence of the defender and goalkeeper, mean ball speed was similar across all four conditions. Only a 2.1% difference existed between the mean ball speeds across the four conditions. As well as significant changes in the means, greater variability (i.e. standard deviations) was found in the forward swing distance, height of release, lateral trunk flexion and the proportion of the total shot from ball pick-up to top of the back swing, when the defender and/or goalkeeper were present than that seen in the control condition. Collectively, these findings could suggest that these national level players exhibited a certain level of functional variability. However, in order to verify this tentative suggestion, an intra-shot analysis and the separation of hit and miss attempts would need to be undertaken. Without this additional analysis, such results could partially reflect noise from the collection and analysis of the kinematic data as well as a-functional variability. A high level of functional variability would allow the participants to adapt their movements both within and across the four conditions and still achieve a relatively high level of performance. Similarly, high levels of functional variability have been observed in skilled discus throwers and pistol shooters (Bauer & Schoellhorn, 1997; Schoellhorn & Bauer, 1998; Scholz et al., 2000).

This ability of skilled performers to maintain high levels of performance under challenging game specific constraints is consistent with the view of Kelso (1995). Kelso indicates that the attainment of high levels of proficiency in a movement (in this case water polo shooting) is illustrated by the process of self-organisation. Self-organisation is the emergence of a stable movement pattern for a particular task (Magill, 2003). Self-organisation is therefore imperative for

the ability of a performer to adapt to the ever-changing constraints present during any human movement. These adaptations result from the practice of individual-individual and individual-environment interactions (Guerin & Kunkle, 2004). This type of practice consequently allows the performer to develop solutions to satisfy the specific constraints under which tasks are performed and master the redundant degrees of freedom (Glazier *et al.*, 2003). The coaches' role is to develop an optimal practice environment that improves an athlete's performance in competition. Coaches' understand that many repetitions of a task are needed to master a skill. This often leads to a focus on the 'perfect' technique or ideal skill, because of this focus practice often becomes devoted to achieving this 'perfect' skill and a majority of practice is, therefore, conducted in the form of closed skills. Consequently, the players do not develop the functional skills to self-organise their movements in the presence of constraints.

It is proposed that the ability of water polo players to adapt their shooting technique to the specific constraints imposed by the defender and/or goalkeeper was achieved by their ability to utilise the perception-action coupling. The perception-action coupling is a cyclic concept demonstrating how movements generate sensory information which can in turn be used to adapt the task movement in relation to the sensory information present to develop skilled behaviour (Chow *et al.*, 2006). Previous studies have examined the coupling between information and action, demonstrating that in both basketball and cricket, skilled performers require specific sensory (perceptual) information to achieve a high level of task performance (Araujo *et al.*, 2004; Renshaw & Davids, 2004). However, it is not currently known as to what type of specifying information is used in the perception-action cycle by water polo players (or athletes in general) during practice and competition. Recent research in cricket has found that the batter uses specifying information from the bowler's arm and wrist to predict the type of delivery and hence, become better prepared to play the appropriate stroke (Renshaw *et al.*, 2004). Similar to the findings of Renshaw *et al.* (2004)**,** it is proposed that water polo shooters may use information from the defender and/or goalkeeper's body or arm to form their movement solutions and maximise the success of their shot.

Coaches' often use part practice, where skills have been decomposed to make them more simple for the performer (Handford, 2002). However, this process does not result in the optimal learning of a skill if the appropriate specifying information is not maintained. Performers need the specifying information to be present in order to form appropriate movement solutions to the specific constraints under which the task is performed. If this information is removed it can alter the coordination of the movement and the potential for successful long-term motor learning. This change in the manner in which the degrees of freedom are coordinated has been observed in cricket batting when a real bowler was exchanged for a bowling machine (Renshaw *et al*., 2004) and during postural pointing when normal visual feedback was supplemented by the augmented visual feedback provided by a laser pointer emission (Keogh *et al.*, 2004). Therefore, coaches' must ensure when decomposing tasks, that they maintain the presence of specifying information and constraints that may potentially be present in competition settings.

## Practical Applications

The findings of this study have implications for coaches and sport scientists designing practice regimes. The key finding is that shooters alter the coordination of their movement in the presence of the defender and/or goalkeeper. Therefore, the most important application of this study is that the nature of the practice environments and the goal of the task need to be matched to that found in competition. In other words, the presence of a defender and goalkeeper will promote the development of movement solutions through the use of the information present. Through incorporation of this game-like approach to skill development in practice, athletes will be well prepared for competition settings. Practice in water polo should, therefore, aim to include a range of shooting activities with the goalkeeper and defender present and then build the complexity of the activity by adding other positional players and tactical play (Chow *et al.*, 2006). Practice of closed skills such as shooting at empty goals should be minimised because it does not provide much functional use within game situations.

Therefore, coaches who incorporate competition specific constraints within the practice environment across a variety of game-specific settings could potentially develop more "game-smart" players. In addition, the use of this multidisciplinary approach may also increase players' adherence to and enjoyment of practice. Finally, coaches should aim to incorporate more of this open-skill practice under game specific constraints in order to develop their players' movement pattern co-ordination for competition settings because subtle manipulation of task constraints in practice are important in shaping a learner's behaviour towards the objective of a task (Yi *et al*., 2005).

The findings from this study may also have important implications for applied sport scientists and in particular, the importance of using appropriate task goals which are specific to competition in research and addressing the game-specific approach to skill movements. Often sport scientists perpetuate the 'perfect' skill approach through the research of misrepresentative tasks in laboratory settings, with an emphasis on specific movements that should occur during a 'successful' trial. Instead sport scientists should aim to identify the many factors interacting with a specific skill and how the surrounding environment and constraints affect that particular skill. The performance of a sports skill within a laboratory setting may alter the performance of the skill, however, this possibility still exists in field settings. It is therefore, the sport scientists' role to provide an environment that matches competition but can still be controlled for data collection.

## Future Research Recommendations

This study is only an initial attempt at understanding how a range of game specific task constraints may influence the water polo shot. For practical uses, research should focus on determining the major impinging constraints in the shooting environment so practice can be conducted under these constraints. Identification of the most important specifying information for players in which to attune is also vital in developing a successful skill in complex settings. Further studies into what information the defenders and goalkeepers use to coordinate their attempts to block incoming shots is also vital in developing an understanding of overall water polo performance. Additionally, determining the

most effective perceptual training systems to develop functional information-movement couplings will assist in optimising practice environments. Such future studies should also aim to assess a wider range of kinematic (spatial and temporal) variables in order to assess coordination to a larger extent than what was supplied within this study. This may be achieved by the use of a three-dimensional (3-D) rather than a two-dimensional (2-D) approach, as used in the present study. In this way, studies in these areas will lead to a greater knowledge base on how to appropriately develop players for competition settings.

## Conclusions

In summary, the findings from this study are important for the water polo community.  These findings highlight the need to design practice environments that are reflective of competition. Overall, this study has enhanced both the theoretical and practical understanding of movement behaviour in the presence of game-specific constraints. The key message is the importance of practice under game specific constraints so that skilled behaviour ensues following the exploration of the interactions between the movements in the appropriate competition environments.

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# APPENDICES

# Appendix 1: Participant Information Sheet

## Participant Information Sheet

AUT
AUCKLAND UNIVERSITY OF TECHNOLOGY
TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

**Date Information Sheet Produced:** 19th November 2004

**Project Title** The effects of game specific task constraints on the kinematics of the water polo shot.

### Invitation

You are invited to participate in a study investigating the effects of the presence of a goal keeper and defender on shooting technique, accuracy and velocity. This study is being undertaken as part of a Masters of Health Science qualification. Participation is completely voluntary and you may withdraw at any stage without giving a reason or being disadvantaged.

### What is the purpose of the study?

The shot at goal is very important component of water polo performance. Therefore coaches and athletes are constantly looking for training methods to improve the shot at goal. Previous research has been conducted in a lab based environment without the use of goal keepers or defenders. Therefore the influences that task constraints such as a defender and goal keeper have on the technique, accuracy and velocity of the water polo shot is relatively unknown. Thus, the findings of the previous research may not be directly related to game performance as the research does not replicate a game situation where goal keepers and defenders will be present. The benefits of this research may therefore include the development of shot training specificity and how technique, velocity and accuracy are affected by these task constraints.

### Can I join the study?

If you are a national level water polo player then you are eligible to participate in this study.

### Costs of participating?

Participants will not incur any monetary costs for participating in this study. You will be required to attend two assessment sessions of approximately one hour each.

### What happens in the study?

This project will be performed over two one hour testing sessions. One hour will be in water assessment of your shots and the other hour for anthropometric measures to be taken on land. You should come adequately rested (12 - 24 hours) from any previous training session. Anthropometric measures including height, weight and arm lengths will be measured. A warm up will be conducted prior to any maximal throws. You will be marked with black markers that are attached to the fingers, wrist, elbow and shoulder of the shooting arm, as well as both hips and shoulders. You will perform 40 shots at goal across four different conditions with the absence and presence of the goal keeper and/or defender. All of these will be maximum effort. You will be filmed from the side, rear, over head and front. Accuracy will be recorded via video analysis of the position of the ball in the goal. Ball velocity will be assessed with a radar gun.

### What are the discomforts and risks?

The risks involved in this study are minimal. You may experience mild muscular discomfort from the number of shots at goal.

### How will these discomforts and risks be alleviated?

Muscular discomfort will be minimised by a warm up and warm down including stretches. If an injury occurs due to unforeseen circumstances, there are doctors and physiotherapists on the testing premises.

### What are the benefits?

These results will improve our understanding of the effects of game specific task constraints, in the form of the defender and goal keeper on the technique, accuracy and ball velocity when shooting for goal in water polo. This information may lead to improved training techniques for shooting to

enhance game performance. It may also highlight potential areas of your shot that you could improve on.

**What compensation is available for injury or negligence?**
The researcher, AUT or the principal supervisor will not be responsible for any monetary loss incurred in the unlikely event of injury. The ACC system, with its limitations, will provide standard cover if you are injured.

**How will my privacy be protected?**
All records will be kept in a locked limited access cabinet. Data will be treated as confidential and will be used only for the purpose of this study.

**How do I join the study?**
If you are a member of the national team and are currently not injured, please contact the researcher to join the study.

**Opportunity to consider invitation**
You will be given time (14 days) to consider this invitation.

**Opportunity to receive feedback on results of research**
You will be provided with a report on the results obtained from the study. Please contact the researcher if you'd like further information or the full report from the study. The results of this project will be published in a scientific journal and presented at a national or international conference.

**Participant Concerns**

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor.

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, madeline.banda@aut.ac.nz , 917 9999 ext 8044.

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Justin Keogh
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justin.keogh@aut.ac.nz

**Approved by the Auckland University of Technology Ethics Committee on** 6/12/2004
**AUTEC Reference number** 04/224

# Appendix 2: Participant Consent Form

## Consent to Participation in Research

**AUT**
AUCKLAND UNIVERSITY OF TECHNOLOGY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

This form is to be completed in conjunction with, and after reference to, the
AUTEC Guidelines

| | |
|---|---|
| Title of Project: | **The effects of game specific task constraints on the kinematics of the water polo shot.** |
| Project Supervisor: | **Justin Keogh** |
| Researcher: | **Katrina van der Wende** |

- I have read and understood the information provided about this research project (Information Sheet dated 19th November 2004.)

- I have had an opportunity to ask questions and to have them answered.

- I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.

- If I withdraw, I understand that all relevant tapes and transcripts, or parts thereof, will be destroyed.

- I agree to take part in this research.

- I wish to receive a copy of the report from the research: tick one: Yes  O No O

Participant signature:  ...............................................................................

Participant name:  .....................................................................

Participant Contact Details (if you would like a copy of the report from the research):

................................................................................................

................................................................................................

................................................................................................

................................................................................................

Date: ...........................................

**Approved by the Auckland University of Technology Ethics Committee on 6/12/2004
AUTEC Reference number 04/224**

Note: The Participant should retain a copy of this form.

# Appendix 3: Ethics Approval

**AUT**

AUCKLAND UNIVERSITY OF TECHNOLOGY
TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

## MEMORANDUM

### Academic Services

| | |
|---|---|
| To: | Justin Keogh |
| From: | Madeline Banda |
| Date: | 13 December 2004 |
| Subject: | 04/224 The effects of game specific task constraints on the kinematics of the water polo shot |

Dear Justin

Your application for ethics approval was considered by AUTEC at the meeting on 06/12/04.

Your application was approved for a period of two years until 13/12/2006.

You are required to submit the following to AUTEC:

- A brief annual progress report indicating compliance with the ethical approval given.
- A brief statement on the status of the project at the end of the period of approval or on completion of the project, whichever comes sooner.
- A request for renewal of approval if the project has not been completed by the end of the period of approval.

Please note that the Committee grants ethical approval only. If management approval from an institution/organisation is required, it is your responsibility to obtain this.

The Committee wishes you well with your research.

Please include the application number and study title in all correspondence and telephone queries.

Yours sincerely

Madeline Banda
**Executive Secretary**
**AUTEC**

cc: Katrina van der Wende, katrina.vanderwende@aut.ac.nz

From the desk of …
**Madeline Banda**
Academic Services
Student Services

Private Bag 92006, Auckland 1020
New Zealand
E-mail: madeline.banda@aut.ac.nz

Tel: 64 9 917 9999
ext 8044
Fax: 64 9 917 9812

# Appendix 4: SAS Code

```
Filename Files ('D:\Justin\KVW_SAS.txt');

  Options PageNo = 1;

  Data ReadData;
    Infile Files expandtabs Firstobs = 2;
      Input Subject trial Cond velocity heightrel fordist lattrunk shld angscore inout lrc shottime
picktobs picktobp fssms fssmp fsrs fsrp fsmrs fsmrp;

if Subject < 1 then delete;
if Subject > 1 then delete;

if Cond = 1 then Def = 1;
if Cond = 2 then Def = 2;
if Cond = 3 then Def = 1;
if Cond = 4 then Def = 2;

if Cond = 1 then GK = 1;
if Cond = 2 then GK = 1;
if Cond = 3 then GK = 2;
if Cond = 4 then GK = 2;

* this will do analysis by condition i.e. 1 to 4;
Proc Sort data=ReadData;
      By  Subject Cond ;

Proc Means NoPrint data=ReadData;
   Var velocity heightrel fordist lattrunk shld angscore inout lrc shottime picktobs picktobp fssms
fssmp fsrs fsrp fsmrs fsmrp;

By Subject Cond;
      Output Out=OutMnAm Mean = velocity heightrel fordist lattrunk shld angscore inout lrc
shottime picktobs picktobp fssms fssmp fsrs fsrp fsmrs fsmrp;
      Output Out=OutStdAm Std = velocity heightrel fordist lattrunk shld angscore inout lrc
shottime picktobs picktobp fssms fssmp fsrs fsrp fsmrs fsmrp;
Run;

proc print data=OutMnAm;
proc print data=OutStdAm;

Proc mixed data=ReadData;
  Class Subject  Cond;
      Model velocity  = Cond  ;
 contrast 'Cond1- Cond2' Cond  1 -1  0  0;
 contrast 'Cond1- Cond3' Cond  1  0 -1  0;
 contrast 'Cond1- Cond4' Cond  1  0  0 -1;
 contrast 'Cond2- Cond3' Cond  0  1 -1  0;
 contrast 'Cond2- Cond4' Cond  0  1  0 -1;
 contrast 'Cond3- Cond4' Cond  0  0  1 -1;

 Proc mixed data=ReadData;
  Class Subject  Cond;
      Model heightrel  = Cond  ;
 contrast 'Cond1- Cond2' Cond  1 -1  0  0;
 contrast 'Cond1- Cond3' Cond  1  0 -1  0;
 contrast 'Cond1- Cond4' Cond  1  0  0 -1;
 contrast 'Cond2- Cond3' Cond  0  1 -1  0;
 contrast 'Cond2- Cond4' Cond  0  1  0 -1;
```

```
        contrast 'Cond3- Cond4' Cond  0  0  1 -1;

Proc mixed data=ReadData;
   Class Subject  Cond;
      Model fordist  = Cond  ;
   contrast 'Cond1- Cond2' Cond  1 -1  0  0;
   contrast 'Cond1- Cond3' Cond  1  0 -1  0;
   contrast 'Cond1- Cond4' Cond  1  0  0 -1;
   contrast 'Cond2- Cond3' Cond  0  1 -1  0;
   contrast 'Cond2- Cond4' Cond  0  1  0 -1;
   contrast 'Cond3- Cond4' Cond  0  0  1 -1;

Proc mixed data=ReadData;
   Class Subject  Cond;
      Model lattrunk  = Cond  ;
   contrast 'Cond1- Cond2' Cond  1 -1  0  0;
   contrast 'Cond1- Cond3' Cond  1  0 -1  0;
   contrast 'Cond1- Cond4' Cond  1  0  0 -1;
   contrast 'Cond2- Cond3' Cond  0  1 -1  0;
   contrast 'Cond2- Cond4' Cond  0  1  0 -1;
   contrast 'Cond3- Cond4' Cond  0  0  1 -1;

Proc mixed data=ReadData;
   Class Subject  Cond;
      Model shld  = Cond  ;
   contrast 'Cond1- Cond2' Cond  1 -1  0  0;
   contrast 'Cond1- Cond3' Cond  1  0 -1  0;
   contrast 'Cond1- Cond4' Cond  1  0  0 -1;
   contrast 'Cond2- Cond3' Cond  0  1 -1  0;
   contrast 'Cond2- Cond4' Cond  0  1  0 -1;
   contrast 'Cond3- Cond4' Cond  0  0  1 -1;

Proc mixed data=ReadData;
   Class Subject  Cond;
      Model angscore  = Cond  ;
   contrast 'Cond1- Cond2' Cond  1 -1  0  0;
   contrast 'Cond1- Cond3' Cond  1  0 -1  0;
   contrast 'Cond1- Cond4' Cond  1  0  0 -1;
   contrast 'Cond2- Cond3' Cond  0  1 -1  0;
   contrast 'Cond2- Cond4' Cond  0  1  0 -1;
   contrast 'Cond3- Cond4' Cond  0  0  1 -1;

Proc mixed data=ReadData;
   Class Subject  Cond;
      Model inout  = Cond  ;
   contrast 'Cond1- Cond2' Cond  1 -1  0  0;
   contrast 'Cond1- Cond3' Cond  1  0 -1  0;
   contrast 'Cond1- Cond4' Cond  1  0  0 -1;
   contrast 'Cond2- Cond3' Cond  0  1 -1  0;
   contrast 'Cond2- Cond4' Cond  0  1  0 -1;
   contrast 'Cond3- Cond4' Cond  0  0  1 -1;

Proc mixed data=ReadData;
   Class Subject  Cond;
      Model lrc  = Cond  ;
   contrast 'Cond1- Cond2' Cond  1 -1  0  0;
   contrast 'Cond1- Cond3' Cond  1  0 -1  0;
   contrast 'Cond1- Cond4' Cond  1  0  0 -1;
   contrast 'Cond2- Cond3' Cond  0  1 -1  0;
   contrast 'Cond2- Cond4' Cond  0  1  0 -1;
   contrast 'Cond3- Cond4' Cond  0  0  1 -1;
```

```
Proc mixed data=ReadData;
  Class Subject  Cond;
     Model shottime  = Cond  ;
 contrast 'Cond1- Cond2' Cond  1 -1  0  0;
 contrast 'Cond1- Cond3' Cond  1  0 -1  0;
 contrast 'Cond1- Cond4' Cond  1  0  0 -1;
 contrast 'Cond2- Cond3' Cond  0  1 -1  0;
 contrast 'Cond2- Cond4' Cond  0  1  0 -1;
 contrast 'Cond3- Cond4' Cond  0  0  1 -1;

Proc mixed data=ReadData;
  Class Subject  Cond;
     Model picktobs  = Cond  ;
 contrast 'Cond1- Cond2' Cond  1 -1  0  0;
 contrast 'Cond1- Cond3' Cond  1  0 -1  0;
 contrast 'Cond1- Cond4' Cond  1  0  0 -1;
 contrast 'Cond2- Cond3' Cond  0  1 -1  0;
 contrast 'Cond2- Cond4' Cond  0  1  0 -1;
 contrast 'Cond3- Cond4' Cond  0  0  1 -1;

Proc mixed data=ReadData;
  Class Subject  Cond;
     Model picktobp  = Cond  ;
 contrast 'Cond1- Cond2' Cond  1 -1  0  0;
 contrast 'Cond1- Cond3' Cond  1  0 -1  0;
 contrast 'Cond1- Cond4' Cond  1  0  0 -1;
 contrast 'Cond2- Cond3' Cond  0  1 -1  0;
 contrast 'Cond2- Cond4' Cond  0  1  0 -1;
 contrast 'Cond3- Cond4' Cond  0  0  1 -1;

Proc mixed data=ReadData;
  Class Subject  Cond;
     Model fssms  = Cond  ;
 contrast 'Cond1- Cond2' Cond  1 -1  0  0;
 contrast 'Cond1- Cond3' Cond  1  0 -1  0;
 contrast 'Cond1- Cond4' Cond  1  0  0 -1;
 contrast 'Cond2- Cond3' Cond  0  1 -1  0;
 contrast 'Cond2- Cond4' Cond  0  1  0 -1;
 contrast 'Cond3- Cond4' Cond  0  0  1 -1;

Proc mixed data=ReadData;
  Class Subject  Cond;
     Model fssmp  = Cond  ;
 contrast 'Cond1- Cond2' Cond  1 -1  0  0;
 contrast 'Cond1- Cond3' Cond  1  0 -1  0;
 contrast 'Cond1- Cond4' Cond  1  0  0 -1;
 contrast 'Cond2- Cond3' Cond  0  1 -1  0;
 contrast 'Cond2- Cond4' Cond  0  1  0 -1;
 contrast 'Cond3- Cond4' Cond  0  0  1 -1;

Proc mixed data=ReadData;
  Class Subject  Cond;
     Model fsrs  = Cond  ;
 contrast 'Cond1- Cond2' Cond  1 -1  0  0;
 contrast 'Cond1- Cond3' Cond  1  0 -1  0;
 contrast 'Cond1- Cond4' Cond  1  0  0 -1;
 contrast 'Cond2- Cond3' Cond  0  1 -1  0;
 contrast 'Cond2- Cond4' Cond  0  1  0 -1;
 contrast 'Cond3- Cond4' Cond  0  0  1 -1;

Proc mixed data=ReadData;
  Class Subject  Cond;
     Model fsrp  = Cond  ;
```

```
    contrast 'Cond1- Cond2' Cond  1 -1  0  0;
    contrast 'Cond1- Cond3' Cond  1  0 -1  0;
    contrast 'Cond1- Cond4' Cond  1  0  0 -1;
    contrast 'Cond2- Cond3' Cond  0  1 -1  0;
    contrast 'Cond2- Cond4' Cond  0  1  0 -1;
    contrast 'Cond3- Cond4' Cond  0  0  1 -1;

Proc mixed data=ReadData;
  Class Subject  Cond;
     Model fsmrs  = Cond  ;
  contrast 'Cond1- Cond2' Cond  1 -1  0  0;
  contrast 'Cond1- Cond3' Cond  1  0 -1  0;
  contrast 'Cond1- Cond4' Cond  1  0  0 -1;
  contrast 'Cond2- Cond3' Cond  0  1 -1  0;
  contrast 'Cond2- Cond4' Cond  0  1  0 -1;
  contrast 'Cond3- Cond4' Cond  0  0  1 -1;

Proc mixed data=ReadData;
  Class Subject  Cond;
     Model fsmrp  = Cond  ;
  contrast 'Cond1- Cond2' Cond  1 -1  0  0;
  contrast 'Cond1- Cond3' Cond  1  0 -1  0;
  contrast 'Cond1- Cond4' Cond  1  0  0 -1;
  contrast 'Cond2- Cond3' Cond  0  1 -1  0;
  contrast 'Cond2- Cond4' Cond  0  1  0 -1;
  contrast 'Cond3- Cond4' Cond  0  0  1 -1;

* this will do analysis by defender i.e 1 to 2 for this indep variables;
Proc Sort data=ReadData;
     By Subject Def ;

Proc Means NoPrint data=ReadData;
   Var velocity heightrel fordist lattrunk shld angscore inout lrc shottime picktobs picktobp fssms
fssmp fsrs fsrp fsmrs fsmrp;

By Subject Def;
     Output Out=OutMnAm Mean = velocity heightrel fordist lattrunk shld angscore inout lrc
shottime picktobs picktobp fssms fssmp fsrs fsrp fsmrs fsmrp;
     Output Out=OutStdAm Std = velocity heightrel fordist lattrunk shld angscore inout lrc
shottime picktobs picktobp fssms fssmp fsrs fsrp fsmrs fsmrp;
Run;

proc print data=OutMnAm;
proc print data=OutStdAm;

Proc mixed data=ReadData;
  Class Subject Def ;
     Model velocity  = Def   ;

Proc mixed data=ReadData;
  Class Subject Def ;
     Model heightrel  = Def   ;

Proc mixed data=ReadData;
  Class Subject Def ;
     Model fordist  = Def   ;

Proc mixed data=ReadData;
  Class Subject Def ;
     Model lattrunk  = Def   ;
```

```
Proc mixed data=ReadData;
  Class Subject Def ;
    Model shld  = Def   ;

Proc mixed data=ReadData;
  Class Subject Def ;
    Model angscore  = Def   ;

Proc mixed data=ReadData;
  Class Subject Def ;
    Model inout  = Def   ;

Proc mixed data=ReadData;
  Class Subject Def ;
    Model lrc  = Def   ;

Proc mixed data=ReadData;
  Class Subject Def ;
    Model shottime  = Def   ;

Proc mixed data=ReadData;
  Class Subject Def ;
    Model picktobs  = Def   ;

Proc mixed data=ReadData;
  Class Subject Def ;
    Model picktobp  = Def   ;

Proc mixed data=ReadData;
  Class Subject Def ;
    Model fssms  = Def   ;

Proc mixed data=ReadData;
  Class Subject Def ;
    Model fssmp  = Def   ;

Proc mixed data=ReadData;
  Class Subject Def ;
    Model fsrs  = Def   ;

Proc mixed data=ReadData;
  Class Subject Def ;
    Model fsrp  = Def   ;

Proc mixed data=ReadData;
  Class Subject Def ;
    Model fsmrs  = Def   ;

Proc mixed data=ReadData;
  Class Subject Def ;
    Model fsmrp  = Def   ;


* this will do analysis by goalkeeper i.e 1 to 2 for this indep variables;
 Proc Sort data=ReadData;
    By Subject GK ;

Proc Means NoPrint data=ReadData;
  Var velocity heightrel fordist lattrunk shld angscore inout lrc shottime picktobs picktobp fssms
fssmp fsrs fsrp fsmrs fsmrp;

By Subject GK;
    Output Out=OutMnAm Mean = velocity heightrel fordist lattrunk shld angscore inout lrc
```

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```
shottime picktobs picktobp fssms fssmp fsrs fsrp fsmrs fsmrp;
     Output Out=OutStdAm Std = velocity heightrel fordist lattrunk shld angscore inout lrc
shottime picktobs picktobp fssms fssmp fsrs fsrp fsmrs;
Run;

proc print data=OutMnAm;
proc print data=OutStdAm;

 Proc mixed data=ReadData;
  Class Subject GK ;
     Model velocity  = GK  ;

Proc mixed data=ReadData;
  Class Subject GK ;
     Model heightrel  = GK  ;

Proc mixed data=ReadData;
  Class Subject GK ;
     Model fordist  = GK  ;

Proc mixed data=ReadData;
  Class Subject GK ;
     Model lattrunk  = GK  ;

Proc mixed data=ReadData;
  Class Subject GK ;
     Model shld  = GK  ;

Proc mixed data=ReadData;
  Class Subject GK ;
     Model angscore  = GK  ;

Proc mixed data=ReadData;
  Class Subject GK ;
     Model inout  = GK  ;

Proc mixed data=ReadData;
  Class Subject GK ;
     Model lrc  = GK  ;

Proc mixed data=ReadData;
  Class Subject GK ;
     Model shottime  = GK  ;

Proc mixed data=ReadData;
  Class Subject GK ;
     Model picktobs  = GK  ;

Proc mixed data=ReadData;
  Class Subject GK ;
     Model picktobp  = GK  ;

Proc mixed data=ReadData;
  Class Subject GK ;
     Model fssms  = GK  ;

Proc mixed data=ReadData;
  Class Subject GK ;
     Model fssmp  = GK  ;

Proc mixed data=ReadData;
  Class Subject GK ;
     Model fsrs  = GK  ;
```

```
Proc mixed data=ReadData;
  Class Subject GK ;
     Model fsrp  = GK  ;

Proc mixed data=ReadData;
  Class Subject GK ;
     Model fsmrs  = GK  ;

Proc mixed data=ReadData;
  Class Subject GK ;
     Model fsmrp  = GK  ; run:
```

# Appendix 5: Results

| | Condition 1 & 2 | | | Condition 1 & 3 | | | Condition 1 & 4 | | |
|---|---|---|---|---|---|---|---|---|---|
| | p value | ES | DOC | p value | ES | DOC | p value | ES | DOC |
| Ball speed (m.s⁻¹) | 0.1740 | 0.085 | ↓ | 0.9926 | 0.022 | ↑ | 0.0561 | 0.452 | ↓ |
| Height at release (cm) | 0.6637 | 0.073 | ↓ | 0.4749 | 0.285 | ↑ | 0.6772 | 0.113 | ↓ |
| Forward swing distance (cm) | 0.1951 | 0.121 | ↑ | 0.9200 | 0.010 | ↑ | 0.2788 | 0.117 | ↑ |
| Lateral trunk angle at release (°) | 0.0944 | 0.284 | ↑ | 0.2972 | 0.240 | ↓ | 0.0735 | 0.375 | ↑ |
| Shoulder angle at release (°) | 0.3971 | 0.229 | ↓ | 0.5638 | 0.140 | ↓ | 0.9382 | 0.009 | ↓ |
| Score out of five | 0.2072 | 0.369 | ↓ | 0.4033 | 0.349 | ↓ | 0.0019 | 1.313 | ↓ |
| Number of goals scored | 0.2425 | 0.313 | ↓ | 0.4043 | 0.364 | ↓ | 0.0005 | 1.373 | ↓ |
| Ball placement | 0.0005 | 1.230 | ↓ | 0.0208* | 0.936 | ↓ | <.0001 | 1.768 | ↓ |
| Shot time (s) | 0.0235 | 0.230 | ↓ | 0.0028* | 0.583 | ↓ | 0.0163 | 0.433 | ↓ |
| Pick up to top of backswing (s) | 0.0026 | 0.439 | ↓ | 0.0037* | 0.579 | ↓ | 0.0004 | 0.697 | ↓ |
| Pick up to top of backswing (%) | 0.0001 | 0.445 | ↓ | 0.0093* | 0.569 | ↓ | <.0001 | 0.961 | ↓ |
| Forward swing start to midway (s) | 0.0950 | 0.211 | ↓ | 0.9253 | 0.011 | ↓ | 0.6931 | 0.073 | ↑ |
| Forward swing start to midway (%) | 0.9239 | 0.015 | ↓ | 0.2432 | 0.334 | ↑ | 0.2432 | 0.188 | ↑ |
| Forward swing start to release (s) | 0.2117 | 0.144 | ↓ | 0.4451 | 0.165 | ↑ | 0.4360 | 0.167 | ↑ |
| Forward swing start to release (%) | 0.7658 | 0.106 | ↑ | 0.5443 | 0.382 | ↑ | 0.8213 | 0.148 | ↑ |
| Forward swing midway to release (s) | 0.6559 | 0.081 | ↑ | 0.2729 | 0.299 | ↓ | 0.5324 | 0.155 | ↑ |
| Forward swing midway to release (%) | 0.1590 | 0.266 | ↑ | 0.9988 | 0.006 | ↓ | 0.3031 | 0.314 | ↑ |

Key: Condition 1 - control condition, no defender or goalkeeper; Condition 2 – defender only;

Condition 3 – goalkeeper only; Condition 4 – defender and goalkeeper

| | Condition 2 & 3 | | | Condition 2 & 4 | | | Condition 3 & 4 | | |
|---|---|---|---|---|---|---|---|---|---|
| | p value | DOC | ES | p value | DOC | ES | p value | DOC | ES |
| Ball speed (m.s⁻¹) | 0.1810 | ↑ | 0.081 | 0.5665 | → | 0.032 | 0.0597 | → | 0.477 |
| Height at release (cm) | 0.7753 | ↑ | 0.037 | 0.9841 | ↑ | 0.004 | 0.7597 | ↑ | 0.068 |
| Forward swing distance (cm) | 0.2279 | ↑ | 0.119 | 0.0207 | ↑ | 0.206 | 0.2354 | ↑ | 0.132 |
| Lateral trunk angle at release (°) | 0.0096 | → | 0.417 | 0.9022 | ↑ | 0.019 | 0.0070 | ↑ | 0.524 |
| Shoulder angle at release (°) | 0.7847 | ↑ | 0.076 | 0.4396 | ↑ | 0.222 | 0.6158 | → | 0.132 |
| Score out of five | 0.6613 | ↑ | 0.134 | 0.0414 | → | 0.613 | 0.0155 | → | 1.066 |
| Number of goals scored | 0.7301 | ↑ | 0.102 | 0.0096 | → | 0.707 | 0.0041 | → | 1.284 |
| Ball placement | 0.1364 | ↑ | 0.547 | 0.0764 | → | 0.529 | 0.0022 | → | 1.181 |
| Shot time (s) | 0.3779 | → | 0.092 | 0.8788 | → | 0.016 | 0.4626 | ↑ | 0.145 |
| Pick up to top of backswing (s) | 0.9049 | ↑ | 0.020 | 0.4744 | → | 0.101 | 0.4058 | → | 0.168 |
| Pick up to top of backswing (%) | 0.1223 | ↑ | 0.149 | 0.2487 | → | 0.101 | 0.0099 | → | 0.417 |
| Forward swing start to midway (s) | 0.0805 | ↑ | 0.213 | 0.0426 | ↑ | 0.279 | 0.7648 | ↑ | 0.058 |
| Forward swing start to midway (%) | 0.0526 | ↑ | 0.247 | 0.2837 | → | 0.124 | 0.0042 | ↑ | 0.410 |
| Forward swing start to release (s) | 0.6213 | ↑ | 0.056 | 0.0483 | ↑ | 0.229 | 0.1300 | ↑ | 0.327 |
| Forward swing start to release (%) | 0.7565 | ↑ | 0.099 | 0.9420 | → | 0.019 | 0.7016 | → | 0.188 |
| Forward swing midway to release (s) | 0.1293 | → | 0.295 | 0.8582 | ↑ | 0.039 | 0.0917 | → | 0.424 |
| Forward swing midway to release (%) | 0.1606 | ↑ | 0.284 | 0.6912 | → | 0.074 | 0.3049 | ↑ | 0.350 |

**Key:** **Condition 1** - control condition, no defender or goalkeeper; **Condition 2** – defender only;
**Condition 3** – goalkeeper only; **Condition 4** – defender and goalkeeper

# Appendix 6: Reliability

Reliability was obtained from the digitised data, and one variable from each of the outcome, linear and angles at release measures.

Ten trials were randomly selected from all participants and conditions. These were as follows:

| Participants | Condition | Trial |
|:---:|:---:|:---:|
| 3 | 4 | 6 |
| 7 | 2 | 5 |
| 4 | 1 | 10 |
| 2 | 1 | 3 |
| 7 | 3 | 1 |
| 9 | 1 | 10 |
| 8 | 3 | 5 |
| 5 | 1 | 1 |
| 3 | 2 | 3 |
| 6 | 3 | 7 |

The intra-class coefficient, Pearson's correlation ($r^2$) and the typical error as a coefficient of variance (%) of all the ten trials of each variable are as follows:

| | Variable | ICC | $R^2$ | CV % |
|---|---|---|---|---|
| **Digitising** | Ball displacement | 0.972 | 0.972 | 13.6 |
| | Shoulder displacement | 0.994 | 0.994 | 2.2 |
| | Hip displacement | 1.000 | 1.000 | 4.0 |
| **Outcome** | Score out of five | 0.926 | 0.892 | 20.5 |
| **Linear** | Height at Ball Release (cm) | 0.949 | 0.949 | 1.1 |
| **Angle at Ball Release** | Lateral Trunk angle (º) | 0.959 | 0.960 | 5.1 |