THE EFFECT OF A RESISTANCE TRAINING PROGRAM ON THE GRAB, TRACK AND SWING STARTS IN SWIMMING

by

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ABSTRACT

Primarily the study aimed to establish the effectiveness of the grab, swing and rear-weighted track starts in swimming. In order to minimise bias of prior learning, twenty-three non-competitive swimmers participated in the study (mean age 19.9 ± 2.4 yrs). Participants learned the techniques for 30 minutes weekly for an eight-week period. Testing involved two maximal trials of each technique in random order. Horizontal and vertical force components from the feet were measured using a Kistler force plate, and by the hands via a hand-bar instrumented with load cells. Video was used to measure temporal and kinematic variables. Analyses of variance and post-hoc tests were performed for each dependent variable. Significant differences were found between the grab and track starts in flight distance, take-off velocity, take-off angle and horizontal impulse, and between the swing and track starts in block time, total time, take-off velocity and vertical impulse. The grab and swing starts were significantly different in block time, total time and vertical impulse. No significant differences were found between any of the starts in flight time or entry angle. Almost all of the horizontal drive came from the legs during the grab start, with little arm contribution. In contrast, the arms contributed just over one-third of the total horizontal impulse in the track start and considerably more vertical impulse than the grab start. Results of the current study demonstrated a greater effectiveness of the track start over the grab and swing starts.

The second part of the study sought to establish the effectiveness of a resistance-training program, aimed at improving vertical jumping ability, on the grab, swing and rear-weighted track starts in swimming. Participants were randomly assigned to a control group (N=11) or a resistance-training group (N=12), who trained three times a week for nine weeks. Pre- and post-testing involved the performance of six dry-land tests – two countermovement jumps (with and without arms), two CES squats (25^0/s and 40^0/s bar speed) and two overhead shot throws (with and without back extension), with the best of three trials being recorded. The three dive techniques were also performed post-test using the same procedures and instrumentation as in part one of the study. A repeated measures MANOVA showed that resistance training significantly improved performance in the dry-land tests ($p < 0.0001$). No significant improvements due to training were found for any temporal, kinematic or kinetic variables within the grab or swing starts. Significant training improvements ($p < 0.05$) were found within the track start for take-off velocity, take-off angle and horizontal impulse of the hands. Results suggested that the improved skill of vertical jumping was not transferred directly to the start, particularly in the grab technique. Non-significant trends toward improvement were observed within all starts for vertical force components, suggesting a need for practising the dives to retrain the changed neuromuscular properties.

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AUTHENTICATION

I hereby certify that this thesis is my own work.

University of Ballarat, March 2000.

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CHAPTER ONE

INTRODUCTION

A fast start is an essential part of competitive swimming, particularly in the shorter sprint races. Thayer and Hay (1984) stated that the dive start makes up 10.5% of the total time in a 50 yard freestyle sprint. By improving the start one can reduce the race time by at least one tenth of a second (Maglischo, 1993), which may be the difference between winning and missing out on a place altogether. The 50m freestyle sprint is an all-out power event beginning with an explosive dive off the blocks (O'Shea & O'Shea, 1991). Therefore, greater muscular leg power and improved jumping ability may be important in reducing the starting time and, consequently, overall race time.

An effective swimming start requires a fast entry into the water, followed by a streamlined position in order to reduce drag and minimise the loss of horizontal velocity (Guimaraes & Hay, 1985). To produce a fast entry, the take-off velocity (the point at which the feet leave the block) must be high without adversely affecting the body position and creating increased body drag. The velocity might be increased by improving the technique or by enhancing the swimmer's jumping power. A minimal time spent on the block may also be beneficial by giving the swimmer a psychological advantage of being in front at the start and diving into smooth water (Juergens, 1994). However, it could be disadvantageous if the decreased force produced on the block, and, therefore the speed of entry, was sacrificed for time. Therefore, a trade-off is required between the time spent on the block and the amount of force produced.

Swimming starts have had several changes in the past 30 to 40 years. Most research has compared different techniques, such as arm-swings versus the grab start. The grab start has been commonly accepted as the most effective technique for about 25 years and the track start is becoming the favoured technique of many swimmers.

Hence, research that investigates biomechanical variables of these two starting techniques, could enhance starting performance. Previous research generally has agreed that the grab start is more effective than the swing start for beginning a race. Specifically, one spends a shorter time on the block with the grab start without significantly sacrificing the speed of take-off (Bowers & Cavanagh, 1975; Roffer & Nelson, 1972; Shierman, 1979; Wilson & Marino, 1983).

The forward track start was originally developed as it was considered that the more forward CG and lower body position would decrease the block time without sacrificing the speed of take-off (Fitzgerald, 1973). However, some studies found that the flight distance and take-off speed were adversely affected (Shin & Groppel, 1986; Stone, 1988). This could perhaps be due to the rear leg contributing little to horizontal force production due to the slight weighting of the leg. Therefore, shifting the body weight backwards (rear-weighted track start) in position over the rear leg could increase the loading of the leg extensor muscles and increase the contribution of the arms to the amount of force production. However, this position requires greater horizontal displacement of the CG on the block, which could increase the amount of time spent on the block.

Recent comparisons of the track start (with the body weight forwards) with the grab start have generally agreed that the track start is slightly quicker off the blocks but equally effective to a criterion distance (Allen, Miller, Pein & Oyster, 1999; Shin & Groppel, 1986; Stone, 1988). No research to date has investigated the effectiveness of the track start with the body-weight positioned over the rear leg.

A swimmer's take-off speed might be improved by changing technique or by increasing the power and jumping ability (Adams, 1986; Lyttle & Ostrowski, 1994). Maglischo (1993) stated that the three requirements for a good start were a fast reaction time, great jumping power and a low resistance during gliding. Whilst little can be done to improve reaction time, the other two factors can be improved through training. There has been considerable research on drag reduction and entry techniques aimed at speeding up the gliding phase of the start (Hay & Guimaraes, 1983), but there has been little research on the contribution of leg power to dive start performance. Some research has shown a significant positive correlation between vertical jumping ability and starting performance (Breed, 1998; Pearson, McElroy, Blitvich, Subic, & Blanksby, 1998; Zatsiorsky, Bulgakova & Chaplinsky, 1979). If streamlining is maximised and maintained, then improving jumping ability and power should increase the take-off speed and enhance performance.

The current study aimed to establish whether the grab, swing or rear-weighted track start was more effective by measuring several temporal, kinematic and kinetic performance variables. The study's second aim was to establish the effect of a resistance-training program, aimed at improving jumping ability, on the diving performance of the three dive techniques.

CHAPTER TWO

REVIEW OF LITERATURE

Introduction

Hay (1988) classified swimming start research into three categories. These were: comparative studies of different techniques (Bloom, Hosler & Disch, 1978; Bowers & Cavanagh, 1975; Gibson & Holt, 1976; Shin & Groppel, 1986; Juergens, 1994; Lewis, 1980; Stone, 1988; Wilson & Marino, 1983); descriptive studies, whereby starting techniques are separated into gross measures such as block time, flight time and distance, and glide time (Arellano, Moreno, Martinez & Ona, 1996; Havriluk, 1983); and, studies investigating the factors that influence the success of a given technique (Breed, 1998; Guimaraes & Hay, 1985; Miller, Hay & Wilson, 1984; Zatsiorsky et al., 1979). Whilst the dive start only makes up a small proportion of a sprint race, any small time gains are advantageous as competitors may be placed within hundredths of a second in a race.

Variables influencing the dive start

The grab start combined with the hole entry method has been adopted widely as the most effective starting technique. Therefore, it may be necessary to analyse other aspects of dive performance in order to find influential variables that can be modified to improve start time. Before this can be done, the start should be divided into gross starting measures such as block time, flight time and glide time. Then, useful information is available for coaches, and key factors affecting the performance of the dive can be identified.

Four studies (Arellano et al., 1996; Breed, 1998; Hay & Guimaraes, 1983; Zatsiorsky et al., 1979) have found that the glide time of the start correlated highly ($p < 0.0001$) with starting time, which ranged from 5.5m (Zatsiorsky et al., 1979) to 10m (Arellano et al., 1996). It accounted for no less than 88% of the variance in the start time in any study. Flight time was a non-significant contributor to start time in all of the studies except Breed (1998), with an '*r*' value of 0.63 ($p = 0.01$). However, it should be noted that the time spent in the air makes up a relatively small proportion of the total start time (with a small standard deviation), which makes the chance of finding significance less likely. Only Zatsiorsky et al. (1979) found the block time to correlate significantly ($r = 0.60$, $p < 0.05$) with start time. This suggested that selection of a shorter criterion starting distance could mean that the influence of the block time increases.

Therefore, the time swimmers spent gliding was considerably more important than the time spent on the block or in the air (Hay, 1993). The time of gliding depended on the glide distance, which varied little between subjects and trials, and was not significant; and, the average glide velocity, which correlated highly with total start time ($r = -0.84$ and -0.91) in the respective studies of Hay & Guimaraes (1983) and Breed (1998). As the glide velocity is dependent on several other factors that occur on the block or in the air, one must not overlook these variables. A biomechanical model (see Figure 2.1) helps to explain the relationship between these factors and provide a rationale for the current study.

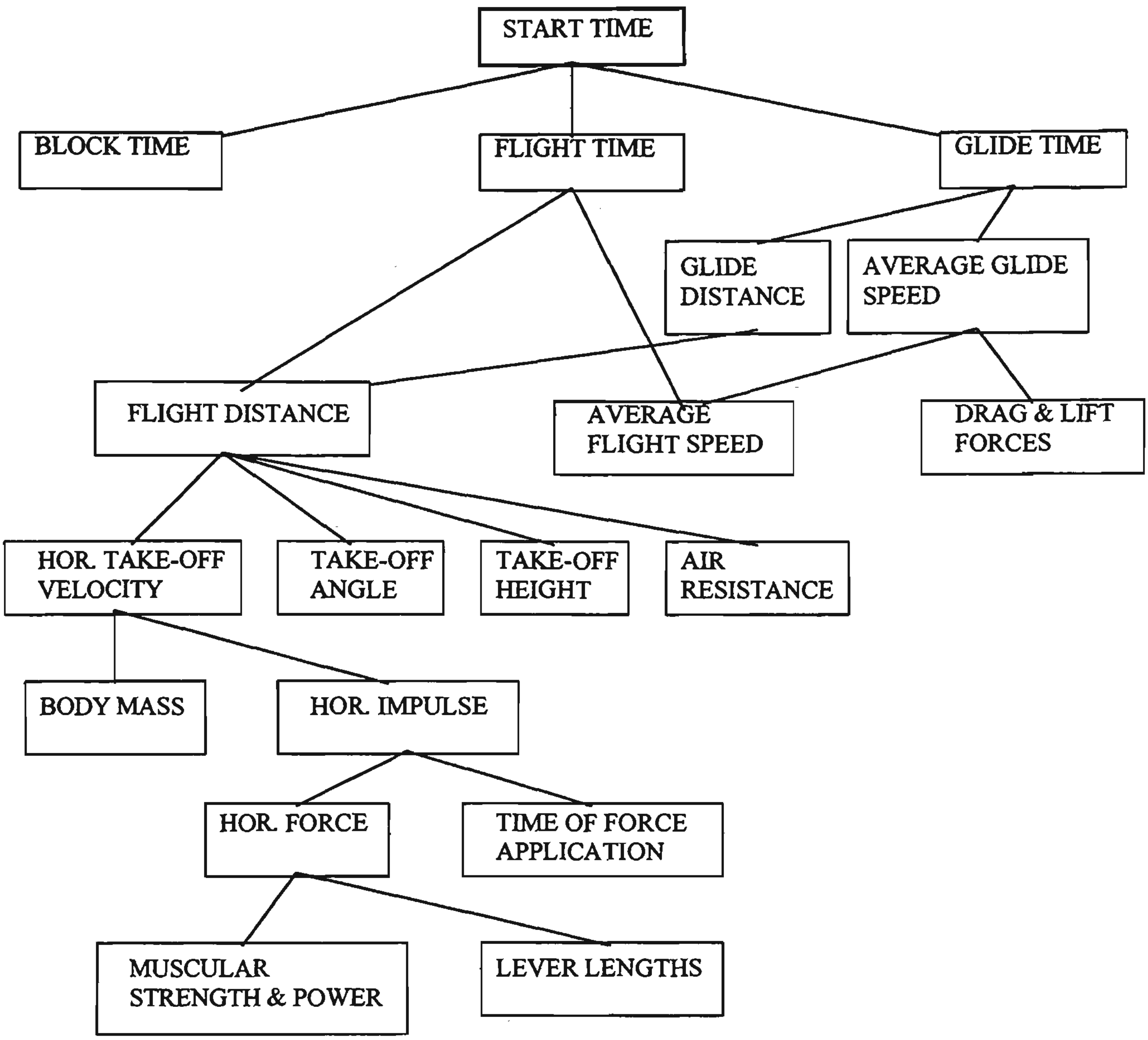


Figure 2.1: The relationship between selected biomechanical starting variables

(Adapted from Hay, 1993)

Similar efficiencies have been observed for different starting techniques and, therefore, biomechanical variables may be more important than the specific techniques (Zatsiorsky et al., 1979). The glide speed is dependent on the horizontal speed in the air and the angle of entry into the water (to minimise the negative forces). Assuming that the air resistance is negligible, then the horizontal flight velocity is directly influenced by the take-off velocity and results from the actions on the block at the start. Whilst block time and flight time were non-significant contributors to starting time in the studies by Arellano et al. (1996) and Hay and Guimaraes (1983), the actions and forces applied during these phases do influence the glide time. Miller et al. (1984) suggested that the time spent in the air should be made longer by increasing the flight distance (by increasing impulse), as the swimmer encounters less resistance during this phase. Therefore, assuming a constant mass of the swimmer, if horizontal impulse on the block was increased, a filtering down effect might occur which, in turn, could increase the velocity of take-off, speed of entry, glide speed and, consequently, decrease the overall start and race time. This could be achieved by improving the starting technique or by increasing the muscular power of the swimmer.

Comparison of starting techniques

The swing start

Originally, the swing start was the most common starting technique, which involved using the arms to gain momentum during a wind-up. This progressed through variations in the preparatory positions for the arms, beginning with extension straight back, followed by the straight back-swing, and then the circular forward and back-swing method of starting.

Three earlier studies compared three different arm swing techniques - a full circular arm-swing, a partial or straight back-swing and an arms-back technique (Lewis, 1980; Maglischo & Maglischo, 1968; Russell, 1967). Russell (1967) used just four experienced male swimmers in his study and found no significant differences between any of the starts for block time or horizontal and vertical take-off velocities using force plate instrumentation. However, such a small sample would reduce statistical power and the likelihood of significant results. Maglischo and Maglischo (1968) used ten experienced competitive swimmers and compared the speed of each technique to a distance of 4.6m using a Dekan automatic performance analyser. The full arm-swing was significantly faster ($p < 0.05$) than the partial back-swing, but was no faster than the arms-back method of starting. No significant differences ($p > 0.05$) in speed were found between the arms-back and partial back-swing techniques.

Lewis (1980) used 10 untrained subjects in order to eliminate any bias due to a preferred or well-practised technique. Individual preference and experience might have affected the results of Maglischo and Maglischo (1968) and Russell (1967), whose subjects were mainly familiar with the full circular arm-swing method of starting. The subjects of Lewis (1980) had 42 practice trials of each technique over a period of 6 weeks. Performance to a distance of 8m was analysed using 16mm cine at 100 frames per second. No significant differences were found between the three swing techniques in the time to reach the 8m distance, take-off speed, angle of take-off, flight time or flight distance. However, the arms-back technique was significantly faster than the full arm-swing method, which also was significantly faster than the straight back-swing method, to leave the starting blocks ($p < 0.05$). As the subjects were non-competitive and were required to swim freestyle at full pace past the 8m distance, it was probable that considerable variation could have occurred between trials in the glide and stroking phases due to no competitive experience. That is, streamlining underwater, surfacing and commencement of stroking could have been more inconsistent than for experienced swimmers. Hence, any differences that might have existed between the actual starting techniques may have been masked.

The studies comparing arm-swing techniques did not generally agree or find any one method to be significantly superior. However, it was generally agreed that the full circular arm-swing method of starting had greater biomechanical advantages. The full arm-swing technique allowed for a greater amount of momentum to be built up prior to the start than other arm-swing techniques (Maglischo & Maglischo, 1968). However, a longer time might be spent on the blocks during the full arm-swing start due to the extra angular distance that the arms must travel (Maglischo & Maglischo, 1968). A further advantage of using a full arm-swing could be that the loading of the leg extensor muscles is greater prior to take-off (Khalid, Amin & Bober, 1989; Shierman, 1979). As the time spent on the block is not a factor in relay races, the full circular arm-swing method of starting is currently the preferred technique during relay changeovers.

The grab start

The circular swing start was replaced by the grab technique as the favoured method of swimming start during the late 1960s (Hanauer, 1967). This involved swimmers grasping the blocks with their hands beside the feet. The technique has been almost universally accepted as the most effective start as it has some potential biomechanical benefits. The body position allows the centre of gravity (CG) to be moved closer towards the water (Gibson & Holt, 1976); the arm pull can increase the pre-tension of the leg muscles during the set position, thereby enabling a greater drive from the legs (Hay, 1993); and, the arms can assist by pulling the body towards the water faster (Hay & Guimaraes, 1983). One further advantage could be that the back extensor muscles contribute more force due to the smaller angle at the hip joint (Bloom et al., 1978).

Variations in the grab technique were developed, involving different hand and feet positions, and degrees of knee and hip flexion. In an attempt to move the CG further forward over the edge of the block, the block was grasped at the sides behind the heels to be in an 'overbalanced' position (Gibson & Holt, 1976; Lewis, 1980). This was aimed at decreasing the response time for the start. One further advantage of this grab start variation could be that the arms may contribute more angular momentum than in the grab start (Gibson & Holt, 1976). Gibson and Holt (1976) found that the grab start tended to be faster off the blocks than the grab variation technique (0.89 s and 0.93 s, respectively), but not significantly so ($p > 0.05$). In contrast, Lewis (1980) showed the variation grab start to be significantly faster off the blocks than the grab start. These different findings could be due to Gibson and Holt (1976) having used 11 experienced competitive swimmers (mean age of 20 years) whereas Lewis (1980) used 10 college male beginners. The subjects in Lewis' (1980) study had no prior preference for any technique, whereas subjects in the study of Gibson and Holt (1976) had become accustomed to using the grab start during their competitive races. Therefore, the latter may have performed it at a comparatively higher level than other techniques. No significant difference was found between the two starts in either study to their respective distances of 7.62m and 8m (Gibson & Holt, 1976; Lewis, 1980).

Woelber (1983) studied a grab start technique variation called the tuck start. The tuck start was designed to allow a lower and more forward CG with improved stability during the set position. To achieve this body position, the swimmer grasped the sides of the block behind the heels of the feet and lowered the body until the knees were tucked to the chest. Woelber (1983) suggested that the tuck start would require less time on the block and in the air than the grab start. However, no statistical investigation was performed and the conclusions were based on theory and observations. No mention of the subject types and numbers or experimental design was made in the theoretical discussion by Woelber (1983). The tuck start would be very unlikely to develop maximal take-off velocity, which is most important in an effective start (Gibson & Holt, 1976; Groves & Roberts, 1972; Miller, Hay & Wilson, 1984), because the leg extensor muscles must overcome a mechanically inefficient position due to the tight knee angle (Breed, 1998). Very little loading or pre-stretch prior to leg extension would be utilised in the tuck position whereas the grab and swing starts use the arms to contribute to force development by increasing the loading of the leg extensor muscles (Pearson et al., 1998).

Many studies on starting techniques have compared the grab and the swing starts (Ayalon, Van Gheluwe & Kanitz, 1975; Bloom et al., 1978; Bowers & Cavanagh, 1975; Gibson & Holt, 1976; Hanauer, 1972; Lewis, 1980; Lowell, 1975; Roffer & Nelson, 1972; Shierman, 1979; Wilson & Marino, 1983; Zatsiorsky et al., 1979). However, there is some disagreement as to the overall effect of the different starts to set distances ranging from 3.66m (Roffer & Nelson, 1972) to 10.93m (Wilson & Marino, 1983). Such differences in criterion distances and experimental designs make it difficult to formulate comparisons and conclusions. All of the studies found that the mean start times for the grab position were marginally faster, or no slower, overall than any of the arm swing positions. Of these, three found the grab start to be significantly faster to a criterion distance (Bowers & Cavanagh, 1975; Lowell, 1975; Roffer & Nelson, 1972). However, Lowell (1975) tested the results at a 93% level of confidence in contrast to the 95% level of the other studies.

Roffer and Nelson (1972) used 16mm cine to measure the performance of nine subjects unfamiliar with the grab start. The grab start (mean=1.31 s) was significantly faster than the circular arm-swing start (mean of 1.41 s) to reach a criterion distance of just 3.66m, with the block phase taking up most of the total time. This mean difference of 0.1 s was equivalent to the differences in the block time of the two starting techniques. No significant differences in flight time were found. No swimmer's body had entered the water by the criterion distance, although the hands of most subjects had just reached the water. Consequently, no part of the glide phase was included in analysis. Therefore, the results did not indicate which start was more effective as water velocities and drag factors were not taken into account.

It was generally agreed that any advantages in total time were due to the significantly shorter time spent on the blocks during the grab start (Bowers & Cavanagh, 1975; Gibson & Holt, 1976; Hanuer, 1972; Lewis, 1980; Lowell, 1975; Roffer & Nelson, 1972). This can be explained in part by the position of the CG which does not have to move as far forward towards the water in the grab position after the starting signal (Bloom et al., 1978). The swing techniques also require extra time for the arms to increase momentum and also loading of the legs. However, in the grab start, the legs are already loaded (or pre-tensed) prior to the starting signal due to the legs pushing in opposition to the arms (Guimaraes & Hay, 1985), which may help to reduce both the reaction time and movement time on the block (Pearson et al., 1998).

Most of the comparative studies discussed so far have examined the block time and total time to a set distance. As the majority agree that significantly less time is spent on the blocks during the grab start than any of the swing techniques, it may be necessary to investigate other factors which could contribute to the difference between the starts. Initially it would appear that, by using the swing technique, more force could be produced as the arm swing increases momentum and therefore impulse. Hence, more horizontal velocity would be produced which should increase the speed of take-off and water entry and the flight distance (Gibson & Holt, 1976; Hanauer, 1972; Lewis, 1980). However, several of the studies investigating other aspects of the start, including horizontal and vertical velocity at take-off, flight time and flight distance, found no significant differences between any of the starting techniques (Ayalon et al., Bloom et al., 1978; Bowers & Cavanagh, 1975; Shierman, 1979). This would suggest that any advantage gained using the grab start is due to a shorter time spent on the blocks and not from any events arising after take-off (Bowers & Cavanagh, 1975).

A hand bar instrumented with strain gauges was mounted in front of the block to measure the forces applied by the hands in the studies of Hay and Guimaraes (1983) and

Cavanagh, Palmgren and Kerr (1975). Hay and Guimaraes stated that "the function of the arm pull was to pre-tense and thus facilitate the drive from the legs" (p.14). Using 24 competitive male high-school swimmers, their study supported this by significantly showing that, the greater the upward and forward impulse applied by the arms (which actually opposes the body's forward motion), the greater the horizontal impulse exerted by the feet. Cavanagh et al. (1975) used just one experienced male subject to study the forces applied by the hands in the grab start. They concluded that the force application by the hands was not directed at accelerating the body horizontally forward; rather, the arms appeared to be used as a "brace" against which the legs were able to press and pre-tense before the hands were released. This would suggest that the contribution of the arm-pull to the take-off compensates for the extra momentum that might be gained by using an arm-swing technique. This would support the findings of Hay and Guimaraes (1983) and Shierman (1979).

Shierman (1979) used six male and five female subjects equally experienced in the grab and circular backswing starts to study the force patterns involved in each starting technique. The side-to-side force components were found to be negligible. The two techniques produced similar amounts of horizontal force. A more detailed analysis showed that the grab start exerted greater downward vertical force in the early preparation phase (simultaneous with the arm pull) and the swing start had greater downward force just prior to take-off. Shierman (1979) suggested that the additional impulse obtained in the grab start due to the initial prestretching of the leg extensors and the push of the arms against the block prior to take-off may be sufficient to make up for the loss of impulse due to the absence of an arm swing movement (Cavanagh et al., 1975; Hay & Guimaraes, 1983). Also, a greater amount of trunk flexion during the grab position may allow a greater force contribution from the hip and back extensor muscles.

Such results would indicate that a trade-off between the time on the blocks and the amount of force generated is required (Gibson & Holt, 1976). Previous studies comparing techniques have primarily been concerned with decreasing the time spent on the block whilst maintaining the amount of force production. However, an athlete could aim to increase leg and shoulder strength and power whilst maintaining the block time. This would have the effect of increasing the velocity of take-off and flight distance of the start by increasing the block impulse (Adams, 1986; Lyttle & Ostrowski, 1994). Either of these improvements would increase the rate of force development, which may be an important aspect of diving that requires further investigation.

The track start

The track start was developed in the early 1970s as a possible superior starting technique over the swing start (Shin & Groppel, 1986). The track start has many of the same principles as the grab start, but employs a wider base of support. Hence, there is greater stability and a lower CG which enables the body weight to be shifted further over the front edge of the block (Fitzgerald, 1973). The lower body position of the track start also can be beneficial in producing a stronger horizontal force during take-off (LaRue, 1985).

The track start in swimming was developed using similar concepts from the crouch start used in track sprinting. The crouch start in track was first used in 1887 in order to move the CG forward of the feet and increase horizontal force production (Desipres, 1973). Moving the weight forward assisted the athlete to overcome the initial inertia of the body. Starting blocks were introduced later to enable greater traction and push-off in the horizontal plane. However, in swimming, FINA (1998) rules state that the block in swimming must have a downward slope of less than 10^0, which minimises the potential horizontal drive of the legs - in particular, the rear leg.

Earlier studies of sprint starts in track mainly investigated the effect of different block spacing and body positions on starting performance (Dickinson, 1934; Gagnon, 1976; Henry, 1952; Kistler, 1934; Menely & Rosemeir, 1968; Schot & Knutzen, 1992; Sigerseth & Grinaker, 1962; Stock, 1962). Henry (1952) identified three categories of sprint-running block spacing - bunched, medium and elongated. The bunched start involved the toes of the rear foot being placed next to the heel of the front foot; in the medium start the knee of the rear leg was placed next to the arch of the front foot; and, in the elongated start the knee of the rear leg was placed next to the heel of the front foot. The toe-to-toe distance of the bunch, medium and elongated starts is about 25-30cm, 40-55cm and 60-70cm, respectively (Hay, 1993), with the variation dependent on the height of the athlete. Medium block spacing repeatedly has been shown to be the most effective start to reach distances ranging from 9.1m to 45.7m (Dickinson, 1934; Henry, 1952; Kistler, 1934; Menely & Rosemeir, 1968; Sigerseth & Grinaker, 1962; Stock, 1962). This may have implications for the track start in swimming, as the block designs in earlier studies did not allow for wider front to back stances (Ayalon et al., 1975; LaRue, 1985; Zatsiorsky et al., 1979) which may provide for a greater horizontal drive from the legs. However, no studies in swimming have investigated the effect of different foot spacing on track start performance.

The track start in swimming has been compared to the grab start by Allen, et al. (1999); Counsilman, Counsilman, Nomura and Endo (1988); Jeurgens (1994); Kirner, Bock and Welch (1989); LaRue (1985); Shin and Groppel (1986); and Stone (1988). The track start has been compared with the grab and swing starts by Ayalon et al. (1975) and Zatsiorsky et al. (1979). When investigating the track start, Ayalon et al. (1975) and LaRue (1985) used a supporting block for the back foot. Whilst Ayalon et al. (1975) used inexperienced subjects and LaRue (1985) used competitive swimmers previously skilled in the grab start, both studies showed the track start to be faster than the grab start to water entry and to a set distance (5m and 4m, respectively). However, only the results of LaRue (1985) reached significance at the 95% level of confidence. The criterion distances used in both studies were not representative of the whole start, as very little of the underwater phase, a highly significant predictor variable of starting performance, was included (Arellano et al., 1996; Breed, 1998; Guimaraes & Hay, 1985). Therefore, this time advantage of the track start may be dissipated over a longer criterion distance.

The modified block has the advantage of increased support for the rear leg to prevent slipping and therefore increasing the horizontal impulse when using the track start (LaRue, 1985). However, current FINA (1998) rules still prevent modifications, such as a rear leg support, to be made to the starting block. Another possible advantage of the modified block was that a medium (or wider based) stance could be used instead of a 'bunched' positioning of the feet. The problem of foot spacing that LaRue (1985) identified should not be a problem with today's blocks, most of which are approximately 60cm in length (Anti-wave). A wider stance tends to create a lower and more stable CM which may enable a greater horizontal impulse than the bunched style where the hips are higher (Jeurgens, 1994). Also, the joint angles of the hip and knee may be biomechanically more efficient for maximising leg drive from the blocks. The studies in track sprinting support this theory by showing that a medium foot stance is superior to a bunched stance (Sigerseth & Grinaker, 1962; Stock, 1962). Henry (1952) stated that the production of force, and as a result velocity, was more important than start time in a fast sprint start. Therefore, perhaps the start generating the most velocity would be superior over an adequate criterion distance such as 10 metres. This also could be true for the swimming start.

Shin and Groppel (1986) analysed the fastest grab and track start trial for 11 skilled varsity subjects (six female and five men) to an 11m distance. The take-off time of the track start was significantly faster ($p < 0.05$) than that of the grab start (0.73 s and 0.77 s, respectively) but was no faster over the criterion distance. This was consistent with the results of others (Allen et al., 1999; Ayalon et al., 1975; Jeurgens 1994; Kirner et al., 1989; LaRue, 1985; and, Stone, 1988). However, the horizontal take-off velocity and flight distance was significantly greater ($p < 0.05$) for the grab start than the track start (Allen et al., 1999; Counsilman et al., 1988; Stone, 1988; Welcher & George, 1998). The most likely reason for this finding is that the track start utilises only one leg to push off the block, which would allow less forward momentum to be generated.

Shin and Groppel (1986) found that the mean times of water entry and time to 11m were not significantly different for the two starting techniques. The mean 11m time of the track start was 0.05 s faster than the grab start. However, a hand-timed stopwatch was used for the 11m time, which may reduce the confidence in the results due to factors such as human error and researcher bias. However, Shin and Groppel (1986) used a hip-marker, in contrast to the CG, for their kinematic measures. This may have contributed to some inaccuracies due to different body positions. There was no significant difference in angle of take-off between the two starts, but the ankle-hip angle at take-off was significantly greater for the track start which may reflect this. The CG is a more accurate representation for projectile motion.

Stone (1988) studied 26 competitive male swimmers and found no significant difference between the two starts in reaction time (using a stand-up response test). This suggested that the shorter block time of the track start was due to decreased movement time. The general agreement in findings is mainly due to the further forward position of the CM and decreased fluctuations in vertical displacement of the track start than the grab start (Fitzgerald, 1973; LaRue, 1985).

Stone (1988) found that the track start was significantly faster than the grab start for block time, time to water entry, water time to the first and second stroke and total time to the first and second stroke ($p < 0.05$). However, the grab start had a significantly greater horizontal flight distance and total distance to the first and second stroke. No significant differences between the two starts were found for the take-off and entry angles. This was supported by Allen et al. (1999), Juergens (1994) and Shin and Groppel (1986), because the velocities at the first and second stroke of the two starts were similar. Therefore, it was concluded that neither start was superior to the other in starting performance (Ayalon et al., 1975; Counsilman et al., 1988; Jeurgens, 1994; Shin & Groppel, 1986).

Zatsiorsky et al. (1979) compared 5.5m times of the track, grab and two swing start variations using 45 highly skilled male subjects. The track start was significantly slower than the three other techniques ($p < 0.05$). No information was provided to describe the specific techniques used, so their findings could have been influenced by the relatively short learning period of three days. As subjects had been experienced in performing the grab and swing starts, the bias of the preferred technique over the 'novel' track start might have influenced the results. However, Ayalon et al. (1975) tested 20 untrained male swimmers with similar findings. The track start with no rear leg support was slower than the grab start to a distance of 5m and significantly slower ($p < 0.05$) than the swing start.

The comparative studies using experienced, competitive swimmers had a training period to allow the starting techniques to be learned and practised (Counsilman et al., 1988; Kirner et al., 1989; LaRue, 1985; Stone, 1988; Zatsiorsky et al., 1979). The starting techniques were practised 100 times each in the study of Counsilman et al. (1988). Other studies simply specified the length of training, such as four 30 minute practice sessions for the grab and track starts (LaRue, 1985); five 45 minute sessions for four techniques (Kirner et al., 1989); and, three daily sessions for four techniques in the study of Zatsiorsky et al. (1979). However, in these studies, the grab start previously had been used repeatedly and favoured during competition. Therefore, it may be questioned whether the skill of the less familiar track start has been acquired to the same level as the grab start.

The studies of Allen et al. (1999), Ayalon et al. (1975) and Juergens (1994) attempted to address the problem of subject bias for a particular technique. Ayalon et al. (1975) studied 20 untrained male swimmers and allowed them a total of 80 practice trials. However, this assumes that all of the techniques will reach a learning plateau following the training period and that the different starts will be performed at the same level of skill. Juergens (1994) selected competitive swimmers who could use the grab and track starts interchangeably in competition, with their proficiency being assessed by three coaches.

Allen et al. (1999) examined eight female and seven male competitive swimmers who were familiar with both the grab and track style starts. The grab start revealed a significantly greater flight distance, when normalised to body height, than the track start ($p < 0.05$) for all subjects. The grab start had a 13.1% increase in flight distance for those preferring the grab start and a 9.6% increase for those with the track start as their preferred method. The vertical force was significantly greater during the track start for subjects preferring the track technique than those preferring the grab start. Men who preferred the track start had a significantly faster start time ($p < 0.05$) for the track start than the preferred grab starters, which was not significantly different for the female subjects. No significant differences were found between techniques for take-off angle, body angle and entry angle.

Other than LaRue (1985), who used a rear supporting block, no study has found the track start to be significantly faster than the grab start to set distances (Ayalon et al., 1975; Counsilman et al., 1988; Shin & Groppel, 1986; Kirner et al., 1989; Zatsiorsky et al., 1979) ranging from 5m (Ayalon et al., 1975) to 11m (Shin & Groppel, 1986). However, most researchers have suggested that the track start is a viable and equally effective alternative to the grab start, depending on the individual (Allen et al., 1999; Counsilman et al., 1988; Kirner et al., 1989; Shin & Groppel, 1986; Stone, 1988). Therefore, it may be necessary to investigate different variations of the track start. No swimming study has looked at the effect of different foot spacing on the start. However, the performance differences may be too small to reach statistical significance once the swimmer has left the block. One area requiring investigation is the effect of body position and CG orientation on the start. Welcher and George (1998) compared the grab start with the two track start variations. The traditional method, with the CG positioned over the front foot, and the slingshot method with the CG positioned over the rear leg towards the back of the block, were studied.

Welcher and George (1998) studied 20 Division I female swimmers, comparing the grab start with the two track start variations while performing three trials of each randomly ordered start to a distance of 5.16m. No kicking or stroking was permitted underwater. The hip was used as a representative point to determine the horizontal velocity of the swimmer at the 5.16m mark. No significant correlation was found between swimmers' fastest starts and their most experienced starts ($r = 0.34$) nor their preferred starts ($r = -0.01$). The slingshot start had the highest velocity of 2.19 m/s, followed by the grab start (2.16 m/s) and the track start (2.11 m/s). This was significant ($p < 0.05$) between the slingshot and track start, but not between the grab and track start, nor between the slingshot and grab start. However, more variables would be required, in particular temporal measures, to make any substantiated conclusions about the starts. The study provides enough questions to warrant further investigation into the effect of CG distribution on the different starting techniques.

Flight and entry technique

Most of the studies mentioned have been concerned primarily with the actions that maximise force production and minimise time on the block. A few studies have investigated the body position during flight and its effect on the start (Counsilman et al., 1988; Gallivan & Hoshizaki, 1987; Guimaraes & Hay, 1985; Hobbie, 1980; Kirner et al., 1989; Wilson & Marino, 1983). A good entry technique is required to maximise the horizontal velocity during the water or glide phase of the start by reducing the drag. Arellano et al. (1996) stated that the training of the swimming start should primarily aim to decrease the drag during the underwater phase. The hole entry technique is one in which the body enters the water at the same point as the hands. Therefore, the swimmer has less frontal area exposed to the water and reduces the forces of drag and lift (Gallivan & Hoshizaki, 1987). This method of flight, combined with the grab start technique, has become the most widely accepted method of starting. When using the flat entry method the body enters the water behind the hands, which might therefore increase water resistance (Counsilman et al., 1988). Whilst theoretically better, there is some disagreement concerning the contribution of the hole entry method towards improved dive performance.

Wilson and Marino (1983) studied the hole and flat entry flight techniques and found the grab/hole entry position to be significantly faster to a 10.93m distance. However, there were no significant differences in times to water entry for any of the techniques. This suggested that the underwater part of the start was shorter, due to the increased angle of entry which reduced the inhibiting forces. Guimaraes and Hay (1985) found that greater heights of entry (of the CG) were associated with shorter starting times, which supports the hole entry method. Swimmers using the hole entry technique spend less time on the blocks as the body does not have to fall as far forward before take-off (Arellano et al., 1996). This is due to a greater angle of the body's CG to the horizontal at take-off. Whilst a shorter time is spent on the blocks during the grab/hole method, more time is spent in the air, which is necessary to prepare for a steeper angle of entry (Counsilman et al., 1988; Hobbie, 1980; Wilson & Marino, 1983). This may help to account for some of the non-significant findings of the comparative starting technique studies mentioned earlier.

Hobbie (1980), however, found no significant differences in times to 6.9m between the different entry methods, whereas Counsilman et al. (1988) and Kirner et al. (1989) found the flat start to be the fastest to 12m and 8m, respectively. Well-trained subjects who generally favoured the flat start were used by Counsilman et al. (1988). Therefore, their findings could have been a result of the swimmers performing their preferred techniques at a higher level of skill. However, when they used less-skilled subjects in the second part of their study, the flat entry start still proved to be more effective - possibly due to its lesser complex nature than the hole entry method. This could have influenced the results in other comparative studies who also used novice subjects with the intent of removing any bias towards a particular technique (Ayalon et al., 1975; Bloom et al., 1978). Kirner et al. (1989) obtained similar results to Counsilman et al. (1988) with the flat start significantly faster than the hole entry to a criterion distance ($p < 0.0001$) and significantly faster to the point of entry ($p < 0.001$). They investigated one step further, and showed that the flat start entry was fastest, regardless of whether participants used a track or grab start ($p < 0.05$).

The results of some studies could have been influenced by the subjects having a preference for one technique over another (Bowers & Cavanagh, 1975; LaRue, 1985; Wilson & Marino, 1983; Zatsiorsky et al., 1979). Hay (1988) stated that comparative studies almost invariably show that the most practiced and/or the least complicated technique yields the best result. Studies comparing swimming start techniques have had some limitations and differences in research design, which have made findings inconclusive and difficult to compare. The most obvious difference was the range of distances to which starting times were measured. These were from 3.6m (Roffer & Nelson, 1972) to 12m (Counsilman et al., 1988) and affected the relative contribution of certain variables to the starting time, such as glide time. The spread or variance within a group (homogenous vs. heterogenous) could also affect the analysis of data. As previously discussed, the sample of subjects can influence findings and pose restrictions on the transferability of results (e.g. novice vs. skilled swimmers). Therefore, the amount of practice allowed to learn a technique could also contribute to the differences in findings.

Physical characteristics of the swimmer

Zatsiorsky et al. (1979) stated that "flight time and glide times for the grab start depend mainly on the jumping ability and size of the swimmer; details of technique (body positions, entry angle, and so forth) are less important." (p. 206). They found that starting efficiency to 5.5m depended significantly on the swimmer's jumping ability (vertical jump, $r = -0.64$), height ($r = -0.67$) and mass ($r = -0.75$). Breed (1998), Guimaraes and Hay (1985) and Pearson et al. (1998) all found similar 'r' values for the height and mass when correlated with a criterion distance. These results were not surprising as mass is an important component of force production (Hay, 1993) and height affects the distance that the CG travels.

Disch, Hosler and Bloom (1979) examined the effect of reach, height and mass on reaction time (RT), movement time (MT) and flight time (FT) of novice females to a 3m distance. Using a stepwise regression analysis, they found that mass accounted for 27.1% of the RT and reach accounted for 24.6% of the FT. None of the variables significantly related to the MT. Only 13 - 29.5% of the variance of RT, MT and FT was accounted for by the combination of anthropometric variables. Therefore, 70 - 87% of the variability in swimming start components was related to other factors, such as leg strength, power or technique, all of which can be directly modified through coaching (Disch et al., 1979). The findings of this study would have been more informative had part of the underwater phase been included in the analysis.

Measurement techniques in swimming starts

The start is of vital importance in separating elite performers (Newble, 1982). Some of the previous methods used to evaluate swimming starts have been unreliable or too awkward to use at the pool side. Many of the older studies in this review employed cinematographic techniques for data collection (Gibson & Holt, 1976; Groves & Roberts, 1972; Havriluk, 1983; Hobbie, 1980). Whilst providing accurate information, there is a considerable delay in the analysis of the results and the costs are high. Bloom et al. (1978) used video successfully for data collection and suggested that they could not have tested as many subjects and trials using cinematographic techniques. Therefore, the low cost, ease of use, short processing time and immediate feedback makes the use of video the preferred method of data collection for researchers in this field (Kennedy, Wright & Smith, 1989).

However, the accuracy of videography versus 16mm cine techniques has been questioned. Kennedy et al. (1989) filmed 20 known coordinates using both methods and found that the cine technique produced a mean error of 4.8mm compared to a 5.8mm error for video. This represented only a 0.05% of a difference of the calibrated field. Whilst it was significantly different, a mean difference of just 1mm over an $8m^3$ field is not important, especially as the fields are usually considerably much larger.

Therefore, the use of video has been widely accepted as being accurate for the purpose of recording human motion (Abraham, 1987; Angulo & Dapena, 1992; Kennedy et al., 1989; Newble, 1982).

When using video and film techniques, errors may exist concerning the accurate recording of the data. The cameras need to be stable and maintained in a fixed position throughout recording. Therefore, it is recommended that at least three fixed reference points are located in the field of view at all times to allow film coordinates to be adjusted in case of film or camera movement (Shapiro, 1978).

Two-dimensional cinematography was considered to be very limiting when analysing complex human motion. Shapiro (1978) suggested that, wherever possible, control points be located throughout the field of motion to reduce any errors concerned with calculating unknown points, or through lens and film distortion. The cameras should be positioned as far as possible away from the action with a high focal length (while maintaining the optimum size of the object field) to increase the resolving power (or resolution in lines mm^{-1}) and decrease the error caused by distortion of distances (parallax error). Alternately, filming an excessively large field or placing the camera too close to the movement plane decreases the resolving power (Susanka, Boswart & Boruvka, 1989). Kohl (1989) suggested that the cameras should be placed about 20 times further away than the real size of the performance space (e.g., a hurdle or throwing circle).

Previous methods of three-dimensional cinematographic measurement required an exact knowledge of multi-camera set-ups and orientation. This required considerable time and may have produced considerable amounts of error (Shapiro, 1978). A method developed in 1971 by Abdel-Aziz and Karara (in Mankoff & Bridges, 1985) allowed filming to be performed by any type of camera without needing the internal measurements or positions of the cameras. The cameras filmed a series of 'control' points with known spatial coordinates in the field of view of all cameras. The control point locations, with respect to a fixed point, were known. The spatial coordinates of unknown points could then be calculated (Wood & Marshall, 1986). This method is known as Direct Linear Transformation (DLT).

The DLT method has been shown to be very accurate and therefore suitable for human motion analysis (Mankoff & Bridges, 1985). Shapiro (1978) showed that the mean error was no more than 5mm in either the X, Y or Z directions when using a static test to calculate unknown spatial coordinates. This error is small when considering the size of the field of view. They also performed a dynamic test to calculate the vertical acceleration of a ball to within 1% to 4% of the g value of $-9.8 m/s^2$. Wood and Marshall (1986) also found the method to be accurate, but significant errors were found when unknown points were extrapolated outside the control point distribution space. Their results also showed that the more control points used the better the point reconstruction values. It is therefore suggested that as many control points as possible be used and be well distributed throughout the space. Therefore, to limit errors in extrapolation, a large reference structure should be used to cover the object area. Whilst the minimum number of control points must be six, Shapiro (1978) stated that "usually 12 to 20 control points will provide the best estimate of the DLT parameters" (p. 199).

The main problem with three-dimensional analysis in swimming starts has been due to the different refractive indices of air, Perspex and water greatly affecting the accuracy of calculating results. Therefore, some means of simultaneously recording the above and below the water actions would be necessary. One way has been to use two cameras, with the underwater one being in a waterproof housing or a viewing pit (if available). This was not always feasible and problems existed in cine techniques with accurate synchronisation of the cameras and the extra time required for analysing the data. McIntyre and Hay (1975) used an inverse periscope with the bottom lens reflecting both the above and under water actions to the upper mirror which reflected the picture onto the film. A few problems were associated with this method. The light intensity for the mediums of air and water were different, which would affect camera settings (when using cine techniques); wave action would partly distort the image; and, there would always be a small part of the swimmer obscured due to the positioning of the optical axis with the horizontal.

Most of the studies mentioned in this review have been concerned primarily with the starting techniques only, rather than as a part of the overall performance. Newble (1982) used a method of video analysis by the pool-side that provided instant data and feedback for the swimmer and coach. It involved using a timing device which counted each cycle in a field (50 Hz) and displayed this time in 0.02 s on a display monitor. It was activated by the starting horn. Therefore, the gross starting times (and turning) could be accurately measured immediately and compared with total times by using the pause or freeze mode on the player.

Specialised biomechanical equipment for digitising spatial coordinates from videotape, such as the Ariel Performance Analysis System (APAS), can be very expensive. Abraham (1987) described a method which used only a special-effects generator (SEG), or a fader, as a specialised device for this purpose. The fader mixed the video signal of the performance with a plain digitising surface, so that the cursor would be superimposed on the image. Placing the cursor on the video signal before it reached the monitor solved the previous problem of digitising errors due to camera and monitor lens distortion. A correlation coefficient of 0.9995 showed this method to be valid through correlating actual coordinates with digitised values. Kohl (1989) suggested that the main error associated with digitising was the random error of reading the individual points. This could be up to 2mm, which is partly due to the cursor parallaxes. This represents between 5mm and 25mm in real size coordinates (Abraham, 1987), depending on the distance of the camera away from the subject.

The sequence of measured coordinates is generally not smooth enough because of random errors in the process of digitisation (Kohl, 1989). Therefore, the smoothing of single coordinates in a sequence is necessary to remove as much error as possible and suppress higher frequency signals, such as noise. The digital filter, such as the Butterworth filter (second order smoothing), and spline functions such as cubic, polynomial and quintic (third order smoothing) are common types of smoothing functions (Kohl, 1989). Cubic spline functions have been recommended as being the most appropriate for smoothing data from projectile motions (McLaughlin, Dillman & Lardner, 1977; Zernicke, Caldwell & Roberts, 1976).

Many different methods of measuring the times of swimming starts have been used in the above studies, including diverse criterion starting distances, using different parts of the body for measurement, and different instrumentation. Bloom et al. (1978) used an above-water video camera to record the block and flight phases of the start to a distance of 3m, assuming that none of the swimmers would have yet entered the water. Other researchers (Arellano et al., 1996; Hay & Guimaraes, 1983; Pearson et al., 1998) have used a bulkhead in the water which stops the timing when it is touched by the swimmer. The main limitation of this method is that the streamlining of the swimmer may need to be altered in order to contact the bulkhead. Bowers and Cavanagh (1975) measured the time by manually operating a stopwatch until the head of the swimmer reached a marker at a 3m distance. This could have several errors associated with it, including the tester's concentration, any bias towards a particular technique by the tester and problems with determining when the head passes the marker (refraction of the light from water to air and the water clarity). One other method of timing the start was used by Zatsiorsky et al. (1979) and Hobbie (1980), which required a line to be attached to the swimmer's bathers so that when it reached the required distance, it pulled a peg out from a switch to stop the timer. This may have inhibited the swimmer physically or psychologically.

Some studies have measured the forces applied to the blocks during swimming starts, including Breed (1998), Shierman (1979) and Zatsiorsky et al. (1979). A force plate mounted onto a starting block was the most common method to measure force and time variables in the X, Y and Z directions. However, the amount of force in the Y and Z directions should be calibrated using trigonometry (cosine rule) to allow for the downward angle of the starting block from the horizontal. Many of the researchers overlooked this, and, therefore, would have had slightly inaccurate values. As the grab start also involves a contribution from the arms, it would be more specific to measure the forces applied with the hands as well as the feet. Hay and Guimaraes (1983) and Stevenson and Morehouse (1979) used a steel bar situated under the front edge of the starting block with strain sensors at either end of the bar to measure the shearing forces applied to it by the hands of the swimmer. Values with less than 6% error in both directions of force had been calculated (Cavanagh et al., 1975), which make it a useful and informative tool for swimming start analysis.

The current study uses a combination of several of the aforementioned methods of measurement, including above-water 2-D video, and force plate and load cell instrumentation in order to measure the dive start variables. An APAS is used for the analysis of the video data.

The relationship between leg power, jumping ability and swimming starts

Adams (1986) stated that lower body power is essential for fast starts and turns in swimming. However, research is limited on lower limb leg strength and power in relation to swimming start performance. Miyashita, Takahashi, Troup and Wakayoshi (1992) conducted one of the few studies in this particular area of swimming research. They found a statistically significant correlation ($p < 0.05$) between leg extensor power and starting performance to 5m ($r = -0.68$), and flight distance ($r = 0.76$). The leg power test involved a reclining seat and a footplate against which the subjects exerted as much force as possible, moving it away at a constant speed. A wide range of swimmers were used, including both male and female, and competitive age-group and open national swimmers, which may have contributed to higher correlation values. The distance to 5m gives little indication of the overall starting performance, as the glide phase, which accounts for a large proportion of the start (Arellano et al., 1996), contributes little over this distance.

Several studies have correlated the standing vertical jump to starting performance over a criterion distance (Breed, 1998; Pearson et al., 1998; Zatsiorsky et al., 1979). Significant correlation values of -0.64, -0.57 and -0.64, respectively, were found in these studies. Breed (1998) used 15 state or national female age-group swimmers, in contrast to Pearson et al.'s (1998) mixed ability and mixed gender group, and the 60 mixed ability male swimmers of Zatsiorsky et al (1979). Similar findings in all of these studies may suggest that jumping ability is an important variable in dive starting performance at most skill levels. Breed (1998) also used a countermovement jump with no arm swing (CMJ) as a more reflective test of leg extensor power than a vertical jump with an arm swing (VJ). However, the CMJ test did not correlate significantly with 7m starting performance, unlike the leg power test and 5m start time of Miyashita et al. (1992).

Counsilman and Counsilman (1994) stated that the use of the VJ to measure explosive power as a potential for speed in swimmers has been highly effective. Counsilman (1977, 1986) and Ballow (1979) successfully used the VJ mainly for the purpose of estimating to which broad category (sprint, middle-distance or distance) of event a swimmer should belong. Counsilman (1977) also suggested that the VJ was an indication of power that could be produced by the rest of the body, including the arms, which produce most of the propulsive force in the freestyle stroke.

There has been some research on the relationship between leg power tests and overall sprint race performance (varying in distances from 22.9m to 91.4m). It would be expected that these tests would correlate more highly with shorter swimming distances. Rohrs and Stager (1991) used the Margaria-Kalamen (M-K) Stair Climb Test as a measure of leg power in age-group competitive males and found it to correlate significantly ($p < 0.05$) to the 22.9m sprint ($r = 0.54$), but not to the 45.7m or 91.4m sprint. This suggested that there was a greater contribution of lower limb power in shorter distances. They also found the M-K test to be significantly correlated with peak power in a tethered swim. The actual test, however, had little resemblance to any of the movement patterns involved in a swimming start and so a more specific leg power test could have resulted in higher correlation values.

In a study by Rohrs, Mayhew, Arabas and Shelton (1990), the VJ was used as a measure of leg power and it related significantly to 22.9m sprint swimming velocity in males ($r = 0.59$), but not in females ($r = 0.07$). This may have been because the female group was considerably more homogenous than the male group, and therefore, it was not clear if the differences were due to gender or the group make-up. More research in this area would be necessary to clarify the issue.

The VJ appears to be a more movement-specific land-based test of power for a swimming start than either the M-K test, as used by Rohrs and Stager (1991) and Rohrs et al. (1990), or the sledge apparatus used by Miyashita et al. (1992). The sledge apparatus was essentially a measure of concentric muscle contraction, rather than involving the stretch-shortening cycle (SSC) of the muscles, which is utilised in the movement-phase of the grab and swing starts. Shierman (1979) stated that the shape of the force curve for the 'gathering phase' of the dive start was similar to the shape of other vertical force curves elicited when performing dynamic movements such as the vertical jump. The VJ has the added advantage of being administered easily in the pool area during training sessions (Counsilman, 1986) and does not involve the time and equipment required by the two other leg power tests mentioned.

The VJ is not solely a test of leg power. Rather, it is a combination of the leg, trunk and arm movements, and jumping skill. Research has found that the arms contribute 10-15% of the height obtained in the VJ (Khalid et al., 1989; Luhtanen & Komi, 1978; Shetty & Etnyre, 1989). A CMJ takes out the arm swing by having the hands remain on the hips throughout the jump. Therefore, it reduces the skill/coordination requirement of the test and focuses the effort more on the leg extensor muscles (Young, 1994a).

In a swimmer's training program, there is little emphasis on developing muscular leg strength and power through progressive overloading exercises (Adams, 1986; Miyashita et al., 1992). This is due to the fact that the large proportion of the race is spent stroking, and only 10.5% of the 50m race time is spent on starting (Thayer & Hay, 1984). However, it has been well documented that the total time in 25 - 100m races largely relates to the efficiency of the start (Counsilman et al., 1988; Hay, 1988).

There has been a need for more research to establish the relative usefulness of land-based leg power training to starting performance, in order to establish the relative value of including leg power exercises in swimmers' training programs. Miyashita et al. (1992) suggested that swimmers must work against high loads and speeds to guarantee maximal voluntary contractions, which are not achieved by using the resistance of water only. The easiest way to increase leg power is to increase leg strength (Miller et al., 1984). However, this could be offset by the risk of increasing muscle mass, which could decrease the swimmer's buoyancy and increase water resistance. Plyometric training can be effective as it can produce increased gains in muscle power whilst minimising the risk of 'bulking up' (Lyttle & Ostrowski, 1994). However, there have been no training studies that show whether power training can improve dive start performance.

Factors determining standing VJ height

Vertical jumping performance is determined by the vertical velocity of the centre of gravity (CG) at take-off. The velocity depends on the mass and the vertical impulse - the result of upward acceleration of the different body segments in jumping (Oddson, 1989). Jumping performance is, in turn, influenced by the amount and rate of force that can be developed by the muscles, the ability to utilise elastic energy in stretched tissues, neural coordination and skill development. This requires the use of the muscles of the feet, calves, thighs, buttocks, back, neck, anterior deltoid, chest and biceps - the muscles used in most dynamic sporting activities (Sargent, 1921).

Strength qualities

Maximal strength contributes to jumping performance. Strength training studies that used subjects without a previous strength training background, found marked improvements in VJ performance (Adams, O'Shea, O'Shea & Climstein, 1992; Bauer, Thayer & Baras, 1990; Clutch, Wilton, McGown & Bryce, 1983; Gemar, 1986; Lyttle, Ostrowski & Wilson, 1996). In contrast, very little improvement has been shown in previously strength-trained individuals (Hakkinen & Komi, 1985). In order to jump higher, the athlete must generate more power by increasing the strength and velocity of the muscle contraction (Adams et al., 1992). The rate of force development (RFD) is a major contributor to take-off velocity and hence VJ performance (Hakkinen & Komi, 1985). This can be calculated by determining the steepest portion of the force-time curve during a maximal strength test (Kraemer & Newton, 1994). Training the VJ with light loads may increase the ability to rapidly develop force (Blattner & Noble, 1979).

Sanders and Wilson (1989) found that the biggest limitation in VJ height is the inability to maintain high forces when the knee angle is close to full extension. This has the effect of a deceleration in vertical velocity prior to take-off. Harman, Rosenstein, Frykman and Rosenstein (1990) found that vertical velocity was maximal 0.03 s before take-off and decreased by 6-7% at take-off. Jozsef and Tihanyi (1992) investigated the effect of different knee joint range on countermovement jump (CMJ) and squat or static jump (SJ) performance. They found that larger knee joint ranges did not result in higher vertical velocities at take-off, showing that a greater knee joint range cannot be utilised to improve performance. The maximal velocity was reached before full knee extension. There was no significant difference between vertical velocity of the SJ and CMJ, even though the velocity of the CMJ increased more sharply than that of the SJ, suggesting a more marked deceleration of the CG prior to take-off. They also suggested that the hip and back extensors may be more important in increasing the vertical velocity than the knee extensors, particularly at the beginning of the concentric phase of a VJ.

The ability of the individual to utilise the SSC affects jumping performance (Komi & Bosco, 1978). During the lengthening of the muscle in eccentric work, elastic energy is stored in the muscle. If this eccentric work is immediately followed by a concentric contraction, part of the stored elastic energy in the muscles can be recovered and used in this positive work (Komi & Bosco, 1978). A higher stretching speed has been associated with movements of smaller amplitudes. Studies have shown that jumps involving movements of smaller amplitude utilise the stored elastic energy more effectively than those involving movements of larger amplitudes (Bosco & Komi, 1983;

Sanders & Wilson, 1989). Sanders and Wilson (1989) suggested that increased amounts of knee flexion may decrease the timing of the larger forces produced by the prestretch in the leg extensors. Increasing the stretching speed and decreasing the pre-stretch range or knee flexion, allows for a more efficient use of elastic energy (Bosco & Komi, 1983). The muscle potentiation has also been shown to increase as the elapsed time between the muscle prestretch and contraction (amortisation phase) decreases (Komi & Bosco, 1978).

A common method of measuring the effect of elastic energy on the leg extensor muscles is to compare a maximal VJ with and without countermovement (Harman et al., 1990; Hudson, 1986; Khalid, Amin & Bober, 1989; Komi & Bosco, 1978; Oddson, 1989; Sanders & Wilson, 1989; Shetty & Etnyre, 1989). However, in some studies the countermovement may not have been rapid enough to create effective elastic loading (Davies & Jones, 1993). The differences in the speed of contraction of the muscles may help to account for the varied findings of these studies.

Skill and coordination of jumping

The timing and coordination of the muscle groups affecting movements of the various segments is important in jumping performance. Bobbert (1990) stated that jumping ability could be improved by either increasing the individual muscle capacity to release energy or to improve the coordination of the different muscle actions. As skilled jumpers are likely to be optimally coordinated, they might benefit more from exercises aimed at increasing muscular power output. However, beginners might benefit more from exercises intending to improve coordination (Bobbert, 1990).

Luhtanen and Komi (1978) used 8 well-trained males to perform segmented jumps and a full SJ. The total performance was 76% of a theoretical maximum calculated from the segmental analysis. Optimal timing of the segments could have increased this to 84 percent. This suggested that special training could improve well-trained athletes' jumping abilities by at least eight percent. This improvement could be considerably more marked in athletes not trained for strength and power. The arm swing and coordination of body segments in the VJ increases the ground reaction force (GRF), which increases the amount of pre-tension in the leg extensor muscles. Therefore, training the skill and coordination of the segmental actions could improve jumping performance.

Hudson (1986) suggested three general patterns of coordination - sequential, simultaneous and modified simultaneous. The study investigated CMJ and SJ performance without an arm swing and found that the VJ was predominantly a simultaneous coordination of body segments. Based on a CIS (composite index of synchronisation), approximately 80% was simultaneous and 20% sequential coordination. In skilled jumping, the sequencing of the segments is less important than the timing (i.e., very small time delays between adjacent segments).

Muscle groups and body segments

The arm and trunk contributions in the VJ can help to increase the amount of loading in the leg extensor muscles. Therefore, the leg extensor muscles can greater utilise the SSC through the extra energy stored in the leg muscles, as a result of the prestretching of the muscles during the preparatory phase (Lafortune & Cochrane, 1988).

Many studies have determined the contribution of the arms to vertical jumping ability by comparing a VJ with and without the use of arms (Lees & Barton, 1996; Shetty & Etnyre, 1989; Khalid et al., 1989; Harman et al., 1990; Davies & Jones, 1993;

Payne, Slater & Telford, 1968). Such studies have attempted to remove the effect of the arms by crossing them to the chest, placing hands on hips, or hands grasping a light bar on the shoulders. Therefore, a CMJ reduces the skill/coordination requirement of the test and focuses the effort on the leg extensor muscles. (Young, 1994a).

Payne et al. (1968) found that the arm swing added an extra late peak on the force-time curve, thereby adding extra force for the propulsion of the CG. The arm swing also increased the rise of height of the CG before take-off by amounts between 12% (Payne et al., 1968) and 21% (Harman et al., 1990). Payne et al. (1968) also observed that the subjects tended to dip deeper when performing jumps without the use of arms.

The arms generally contribute 10 to 15% of the height achieved in a VJ (Harman et al., 1990; Khalid et al., 1989; Luhtanen & Komi, 1978; Oddson, 1989; Shetty & Etnyre, 1989). Through the use of modified vertical jumps, Luhtanen and Komi (1978) investigated the segmental contributions to VJ performance and found that knee extension, plantar flexion, trunk extension, arm swing and head swing contributed 56%, 22%, 10%, 10% and 2%, respectively. However, Ramey (1982) suggested that arm movement contributed 30-40% of the jump height. This high proportion was probably due to using a different interpretation, which involved comparing the peak forces produced when using arms (3.7 times body weight) against no use of arms (2.5 times body weight). Therefore, the VJ should not be used as a measure of leg power as it requires the athlete to coordinate various muscle groups other than the leg extensor muscles (Shetty and Etnyre, 1989).

Narita and Anderson (1992) conducted the only study of the effects of upper body strength training on VJ performance. They found that a seven week training program for the shoulder flexor muscle groups significantly improved VJ height in female varsity volleyballers. It was concluded that the improvement in VJ performance was due to a greater angular momentum of the arm swing and not shoulder flexion velocity or acceleration.

The difference between jumps with or without swinging the upper extremities is due more to higher strain on leg extensors than kinematical changes in movement executed by lower extremities (Khalid et al., 1989). The ground reaction force decreases below body weight as a countermovement is initiated. It has been shown through the use of force plates, that the unweighting during a CMJ is greater when the arms are not used (Harman et al., 1990; Khalid et al., 1989; Payne et al., 1968).

Lees and Barton (1996) investigated the contribution of arms using a relative momentum approach, which quantified the momentum of each free limb relative to its joint attachment to the body. They found that, in a CMJ, the arms contributed to 12.7% of the body's total vertical momentum. Their definition ignores negative momentum, whereas other studies did not. The advantage of the arm swing being applied downwards before being exerted upwards is to apply more stress to the supporting legs. This highlights the importance of timing and coordination of limb actions to maximise their contribution to upward motion. Shetty and Etnyre (1989) found that the arms contribute 15% of the total power and 6% to the vertical velocity at take-off. As the arm movement is a skilled action, unskilled jumpers should not use the arms in testing for jumping ability.

Davies and Jones (1993) found that the arm swing had a greater effect on jumping performance than a countermovement. The arms significantly increased performance in both the VJ (15%) and SJ (13%), but found no significant difference between the jumps with or without the use of arms. However, they found it difficult to completely prevent a dip during the SJ, which may have affected their findings. Harman et al. (1990) found that the arm swing improved vertical ground reaction impulse by 10% in comparison to 3% produced by a countermovement. The arms also increased the rise of height of the CG by 21% when compared with the countermovement's contribution of 6 percent. Payne et al. (1968) found that the arm swing added 12% to the CG's rise of height before take-off. Davies and Jones (1993) suggested that the effect of the arm swing decreases proportionally as the performance level increases.

Training to improve vertical jumping

Traditional strength training, explosive weight training, plyometric exercises and Olympic lifting can be effective for improving vertical jumping performance. However, the most effective form of training may be dependent on the individual athlete and their relative strengths and weaknesses (Kraemer and Newton, 1994). For example, athletes with a great strength base may benefit more from training at faster contraction velocities (Baker, 1996), whereas athletes with lower strength levels may benefit from virtually any form of training (Bauer et al., 1990; Clutch et al., 1983). Most studies that compared different training methods in non-strength trained subjects found that each method (WT, plyometrics or combined methods) improved VJ performance, but no one method was significantly better another (Adams et al., 1987; Bauer et al., 1990; Blattner and Noble, 1979; Clutch et al., 1983; Lyttle et al., 1996).

The fast-twitch muscle fibres are mainly responsible for dynamic performances such as jumping and, therefore, when training for strength, heavy loads must be used in order to ensure the recruitment of all motor units (Wilson et al., 1993). However, training with only heavy loads may produce an adaptation specific to the slow velocities used in lifting these loads. Hence, it is suggested that when training for jumping, the movement should be as explosive as possible (Kraemer and Newton, 1994).

Plyometric training may improve RFD and, therefore, power. Dynamic weight training (i.e., relatively light loads at a high speed) is designed to produce a higher mechanical power output of the muscles. It has been suggested that neuromuscular adaptations contributing to explosive power may occur very early in a training program, sometimes within two to four weeks (Adams et al., 1992; Gemar, 1986). Wilson et al. (1993) tested 64 previously weight-trained subjects after they had participated in 10 weeks of either traditional squat strength exercises, depth jumps (DJ) or explosive weight training at 30% of 1RM. Whilst all experimental groups produced significant improvements in CMJ and SJ performance, the explosive weight training group improved significantly more than the other two groups in both the tests. This would support the specificity theory that plyometrics increase the ability to utilise the elastic and neural benefits of the SSC.

Bauer et al. (1990) trained unskilled jumpers using a variety of training modalities - free weights, hydra gym, plyometrics, hydra gym/plyometrics, free weights/plyometrics. All training groups significantly improved in VJ height after 10 weeks of training, but no one group improved significantly more than any other in jumping performance. Similar conclusions were made by Blattner and Noble (1979) following their three day per week (3DW) eight-week training study. No significant difference existed between an isokinetic (hydra gym) squat and DJ training group in improving VJ height.

Adams et al. (1987) studied 12 to 15 year old males and found no significant gains in VJ performance after 10 weeks of training in either a weight-training (WT)/max VJ or WT/drop jump (DJ) group. This may be due to the maturation of the subjects or because the post-testing was performed just three days after the completion of the training. Brown, Mayhew and Boleach (1986) found that a 3DW DJ program significantly improved VJ height, but not CMJ height. After a period of 12 weeks in 15 year old male basketballers, by comparing the relative increases in the CMJ and VJ, it was suggested that approximately 57% of the VJ gain was due to jumping skill improvement and the remainder from strength increases. However, it was not entirely clear how the authors arrived at this figure.

Using a theoretical model, Bobbert and Van Soest (1994) found that, by strengthening the muscles without changing the timing of the actions, VJ height decreased rather than increased. Baker (1996) suggested that elite strength athletes do not seem to improve VJ performance even when maximum squat strength increases. However, studies have shown that strength weight training can improve VJ performance in athletes without a strength training background (Adams et al., 1992; Bauer et al., 1990; Clutch et al., 1983; Gemar, 1986; Wilson et al., 1993). However, no comparative study has shown that traditional weight training for strength is any better at improving jumping performance than any other training method.

Training programs aimed at improving jumping performance should include exercises that allow athletes to practise with their changed muscular properties, in order to optimise their timing (Bobbert & Van Soest, 1994). This would support the idea that strength training, accompanied by high-velocity training (i.e., plyometrics), is the most effective way of improving VJ ability (Adams et al., 1992; Bauer et al., 1990; Lyttle et al., 1996). Adams et al. (1992) found that a squat strength/plyometric training group showed almost three times as much improvement in VJ performance than either a squat strength or plyometric six-week training group. This finding was in agreement with Lyttle et al. (1996), who found that a WT/plyometric training group tended to produce superior performances in SSC movements than a maximal power training group. This supports the theory of "improving VJ by enhancing both the contractile and stretch reflex properties of the muscle rather than undertaking unidirectional training alone." (Baker, 1996, p.133).

Drop jumping as a form of plyometric training has been shown to be an effective method of improving VJ performance in both skilled and unskilled jumpers (Bobbert, 1990). However, comparisons are difficult because of differences in study design, duration of training period, frequency of sessions, number of repetitions per session, intensity of exercises and the jumping techniques used. As Bobbert (1990) stated, there is no clear pattern in the associated DJ training studies regarding their effectiveness, particularly when using unskilled subjects. Therefore, problems still exist in terms of designing the most effective DJ training program for maximum improvement in VJ performance.

Poole and Maneval (1987) conducted one of the few studies on the effect of the frequency of plyometric training. They found that 2DW DJ training was significantly better in improving VJ performance than 3DW DJ training for a period of 10 weeks. It has been suggested that DJ training for 3DW may not allow sufficient recovery time between sessions (Bobbert, 1990). However, the 10-week training period did not produce a performance plateau in either group, suggesting that a longer training period was required in order to reach optimal performance.

Drop heights of about 40cm are the most effective in improving VJ performance (Brown et al., 1986). However, Blakey and Southard (1987) found no significant differences between a WT group, WT/1.1m DJ group and a WT/40cm DJ group after eight weeks of training. This was despite all training groups significantly improving in a test of dynamic leg strength and an M-K stair-climb test. A 16-week training study by Clutch et al. (1983) supported these findings. Whilst VJ performance improved by an average of 8.4cm, there were no significant differences between a WT/VJ training group, WT/0.3m DJ group and a WT/0.75-1.1m DJ training group. It was concluded that neither the athlete's level of strength nor the height of drop altered the resultant training effects of depth jumps. This could mean that athletes might receive benefits of a combined DJ/weights program without the added possibility of injury due to greater drop heights. However, the tests used by Blakey and Southard (1987) were not movement-specific to the DJ. Therefore, they might not have been able to show performance differences between the groups due to training effects.

Holcomb, Lander, Rutland & Wilson (1996a) stated that the DJ may not adequately train the hip extensors, as they contribute considerably more when performing a VJ. This could partly explain why many studies have not shown that DJ training is significantly better than any other training method in improving VJ performance. However, the DJ might decrease the length of the amortisation phase which increases the power output of the muscles (Holcomb, Lander, Rutland & Wilson, 1996b). This is even more likely when a bounce DJ is used (Bobbert, 1990), which is differentiated by a small amplitude movement (i.e., shallower knee bend) and a shorter contact time. This is in contrast to the countermovement DJ (CDJ) whereby the effects of the pre-stretch are less pronounced, but the movement has a greater similarity to a regular vertical jump. Therefore, repetitions of the CDJ could improve the coordination of jumping (Bobbert, 1990).

In designing a training program specific to jumping, it might be necessary to emphasise the most deficient component of an individual's jumping ability in order to achieve the greatest possible gains (Kraemer and Newton, 1994). The concept of periodisation should be used in a program, with the preparation phase aimed at improving the absolute strength of associated muscles used in jumping. Prior to the competition phase, more specific neural training would be necessary, such as exercises emphasising high velocities and rapid force development with specific movements (Kraemer and Newton, 1994). During the competition phase, the maintenance of all aspects of jumping performance is important. This is in agreement with Bauer et al.

(1990) who suggested that a plyometric program should be phased in once sufficient lower extremity strength has been achieved.

Although there has been much research in comparing the relative effects of different training methods on jumping performance, many questions still remain unanswered. What method of training is the best for improving VJ performance in untrained and trained athletes? What height of DJ is the best? What length of training period is required for maximal gains? The current study aims to maximise vertical jumping performance by using common training principles and then investigate the effect any jumping improvement may have on the grab, swing and track starts in swimming.

CHAPTER THREE

STATEMENT OF PURPOSE

The purpose of the study was twofold. Firstly, the study sought to establish whether there were any significant differences between the grab, swing and track starts in several temporal, kinematic and kinetic variables. Secondly, the study aimed to examine whether a resistance-training program for improving jumping ability had affected selected performance variables of the three starting techniques.

SIGNIFICANCE OF THE STUDY

Using a number of performance variables, the current study compared the effectiveness of the rear-weighted track start with the grab and swing starts. These are currently the most frequently used start techniques in swimming races and during relay changeovers. Previous studies have compared the front-weighted track start with the grab start and have generally agreed that the track start is slightly quicker off the blocks but has no advantage to a criterion distance due to a slower take-off velocity. Such studies have been inconclusive and only compared temporal and kinematic variables, such as velocity and time (Shin & Groppel, 1986; Kirner, Bock & Welch, 1989; Stone, 1988; Welcher & George, 1998). The current study investigated the mechanics and force contributions of the techniques. If the rear-weighted track start proved to be more effective than the currently preferred techniques used in starting and relay changeovers, then it would suggest that coaches and swimmers should practise the start in training as an alternative method of starting.

Thayer and Hay (1984) stated that the dive start makes up 10.5% of the total time in a 50 yard freestyle sprint. As diving requires an explosive push-off, an improvement in leg extensor power and jumping ability should increase the velocity of take-off and the flight distance. Assuming that the time on the block is not increased, overall race time also could be reduced. If there is a significant improvement in starting performance due to improved jumping ability, it would suggest to swimmers that they should include explosive leg exercises during training sessions to increase leg power and jumping ability.

Very little research has investigated the effect of leg power and jumping ability on starting performance. Limited research has shown positive correlation between jumping ability and starting performance (Breed, 1998; Miyashita et al., 1992). Other research has shown a positive correlation between jumping ability and swimming performance (Ballow, 1979; Counsilman & Counsilman, 1994; Rohrs et al., 1990), but no studies to date have investigated the effect of a resistance-training program on starting performance.

Currently, little time is spent developing muscular leg strength and power in a sprint swimmer's training program. The results of this study could have implications for the swimming coach by providing information relating to the value of training jumping ability for sprint swimmers. Therefore, it would be necessary to find out if improvements in jumping ability lead to improved starting performance in order to justify a training program.

RESEARCH HYPOTHESES

PART ONE: A pre-intervention comparison of three diving techniques

1. The flight distance will be significantly greater for the track and swing starts than the grab start, but not significantly different from each other.

2. The resultant take-off velocity will be significantly greater for the track and swing starts than the grab start, but not significantly different from each other.
3. There will be no significant differences between any of the starts in their angle of take-off and angle of entry.
4. The block time and total time will be significantly shorter for the grab and track starts than the swing start, but not significantly different from each other.
5. The flight time will be significantly greater for the track and swing starts than the grab start, but not significantly different from each other.
6. The horizontal and vertical impulse will be significantly greater for the track and swing starts than the grab start, but not significantly different from each other.
7. The grab start will have greater vertical hand force and impulse than the track start, but less horizontal hand force and impulse in the positive direction.

<u>PART TWO</u>: The effect of resistance training on swimming starts

1. The resistance-training group will improve significantly more in all six dry-land tests then the control group following the nine-week intervention.
2. The flight distance and resultant take-off velocity will increase significantly in all three techniques due to the training intervention.
3. Temporal measures will not be significantly different for any of the starts due to the training intervention.
4. Force and impulse components will increase significantly in all three starts due to the training intervention.

DEFINITIONS

Track start:

A split stance of the feet with the body mass positioned over the rear leg of support.

Grab start:

One hand placed on top of the other with the block grasped between the feet.

Swing start:

Beginning with the arms pointing vertically downwards, the arms are swung forward and upward, then backward and downward to complete a full circular arm swing.

Take-off velocity:

The resultant velocity of the CG at the instant the feet left the starting block (the first video field in which the toes lost contact with the block). The resultant vector was calculated from the horizontal and vertical velocity components, found by digitising.

Flight distance:

The horizontal distance from the edge of the pool to the point of finger entry into the water.

Take-off angle:

The angle with respect to the horizontal at which the swimmer's centre of gravity (CG) was moving at the instant the feet left the block. The angle was calculated from the path of the CG.

Entry angle:

The angle measured at the point of finger entry into the water between the horizontal and the fingertips-to-hip line.

Block time:

The time taken from the starting signal to the moment at which the feet leave the block.

Flight time:

The time taken from the moment the feet leave the block until the moment of finger entry into the water.

Total time:

The time taken from the starting signal to the moment of finger entry into the water (block time + flight time).

Leg extensor power:

The muscular power of the leg extensor muscles as inferred from the jump height obtained in the countermovement jump.

Jumping ability:

The height of the jump achieved during a vertical jump (with a countermovement and the use of an arm swing).

Centre of gravity (CG):

The point at which the body's mass is centred.

Stretch-shortening cycle (SSC):

This refers to the sequence of eccentric (muscle lengthening) and concentric (muscle shortening) contractions of the leg extensor muscles as used in jumping.

DELIMITATIONS

1. All of the participants were non-competitive swimmers in order to reduce the effect of performing preferred or well-practised techniques at higher levels of skill.
2. No underwater analysis was performed and so a criterion measure to a set distance could not be used. It was considered that too much variation within participant trials would exist in the underwater phase due to their inexperience. Therefore, each variable was considered to be a dependent variable for the purpose of analysis.
3. Two dimensional video and force analysis was performed as the dives were considered to be primarily single-planar movements. Lateral force components were not analysed as they were considered to be negligible.
4. A practice period of eight half-hour sessions was used, which totalled 80 practice trials of each technique. This should have been sufficient to allow the dives to be performed at a good level of skill and coordination with equal competency in each of the three techniques.

5. Participants performed three trials for each dry-land test. This should have ensured their best performance in each test.

LIMITATIONS

1. The sample was limited to twenty-three females. The results could only be generalised to non-competitive female swimmers.
2. The video cameras operated at a frequency of 50Hz, and therefore video time frames were measured to an accuracy of 0.02 s.
3. Some of the participants may have learned the dry-land testing techniques more easily and, therefore, could better utilise the elastic properties and function of their neuro-muscular system.
4. The overhead shot throws were unfamiliar to most participants, so they may not have been performing these at an appropriate skill level due to the limited practice time.
5. During the intervention period, the participants' activities outside of training time could not be controlled, which may have had an adverse or enhancing effect on the post-test results.

CHAPTER FOUR

METHODOLOGY

Sample selection

Twenty-eight female students from the University of Ballarat volunteered as participants in the study. Prior to the study, participants were required to complete an informed consent form (see Appendix A). Five participants withdrew from the study throughout its course for various reasons (N = 23). The participants were studying in Physical Education and Human Movement courses and were enrolled in a swimming unit. The participants were all competitive athletes from a range of sporting disciplines, including netball, tennis, basketball and running. This was considered important, as it was necessary that all participants would acquire equal standards of the techniques in each of the starts in order to minimise performance bias.

Table 4.1 summarises the descriptive data for the sample group. The complete set of individual data is attached as Appendix B.

Table 4.1: Participant Descriptive Data

Variable	Mean	Std Dev	Minimum	Maximum
Age (years)	18.9	1.5	17.6	29.4
Mass (kg)	64.9	5.2	54.5	78.0
Height (cm)	166.1	6.6	154.5	179.0

Procedures and instrumentation

Dive technique training

Prior to the pre-testing sessions, participants were taught the techniques of three dives over three 20 minute sessions. The dives were the grab, swing and rear-weighted track starts. Following this initial learning period, participants were supervised and coached whilst practising the techniques during one 30 minute session a week for a period of eight weeks. Ten dives of each technique were performed during each session following a light warm-up of swimming in the pool. Participants were videotaped during weeks two and five of training to assist with learning and feedback.

The final training session was a simulation of the actual testing session. A warm-up consisting of five minutes of light swimming in the pool and three practice trials of each technique were performed. The starting commands as used in competitive racing were used for each trial. Following the warm-up, participants were videotaped performing two trials of each diving technique. A video recorder (Panasonic MS-5) was positioned perpendicular to the horizontal plane of the dive so that two-dimensional block and flight starting components could be later analysed.

The videotape was viewed and assessed by two independent competitive swimmers/coaches who were not aware of the purpose of the study. The assessors independently viewed each trial. Participants who did not perform technically adequate starts for each dive were excluded from the study (N=2). The three starting techniques are described below.

1. Grab start:

Participants stood with feet shoulder width apart and the distal joints of the toes over the front edge of the block. One hand was placed on top of the other with the distal finger joints grasping the underside of the block's front edge, between the feet. The legs were bent slightly with the arms straight (see Figure 4.1). On the command of 'take your marks', participants pushed upwards with their legs until almost straight in order to develop pretension in the muscles. On the starting signal, the body was pulled down and forward towards the water until the legs were flexed to about 90^0. The head was then lifted as the body was extended forcefully and explosively. Once full extension of the body was reached, the chin was tucked to the chest to prepare for a more efficient entry into the water.

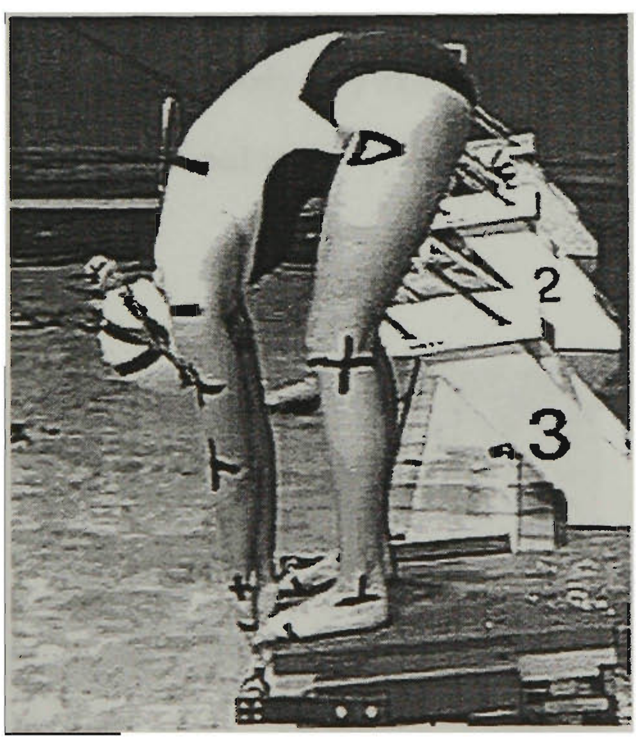


Figure 4.1: The grab start

2. Track start:

The track technique used in this study was rear-weighted. Participants stood with the ball of one foot close to the back edge of the block, with the distal toe joints of the other foot over the front edge of the block. This represented a medium track stance of approximately 50cm (front toe to back toe distance). The distal finger joints were placed under the front edge of the block at shoulder width apart. Most of the body's mass was positioned over the back leg with the arms preventing the body falling backwards. Recent changes to the rules (FINA, 1998) allowed the swimmers to begin in this starting position. On the command of 'take your marks', the body mass was lowered slightly and shifted as far back as possible with the arms remaining straight. The leg muscles were pre-tensed with knee angles of approximately 150^0 for the front leg and 90^0 for the rear leg (see Figure 4.2). On the starting signal, participants pulled back hard against the block keeping the arms straight and propelling the body forwards as quickly as possible. The head was lifted just prior to the hands leaving the block and was then tucked to the chest as the body fully extended. One hand was placed on top of the other to prepare for a streamlined entry.

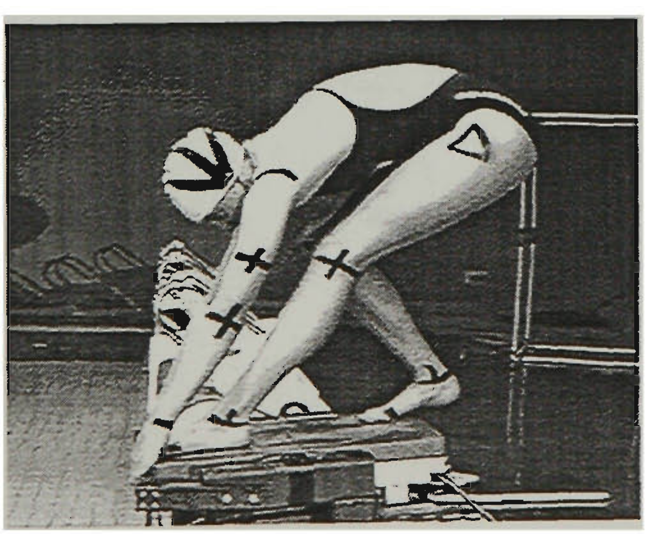


Figure 4.2: The track start

3. Swing start:

Participants stood with feet shoulder width apart and the distal joints of the toes over the front edge of the block. The legs were slightly bent with approximately 90^0 of flexion at the hip joint. The upper body was approximately parallel to the surface of the water with the arms hanging vertically downward (see Figure 4.3). The muscles were tensed on the command of "take your marks". On the start command, the arms were swung forwards and upwards, then backwards and downwards until a full circular arm swing had been performed. During the upswing of the arms the upper body stayed close to horizontal. As the arms swung down and back, the body started to fall towards the water with the knees bending to approximately 90^0. The head was then lifted as the legs began to extend. At full extension of the body the chin was tucked to the chest and one hand was placed on top of the other.

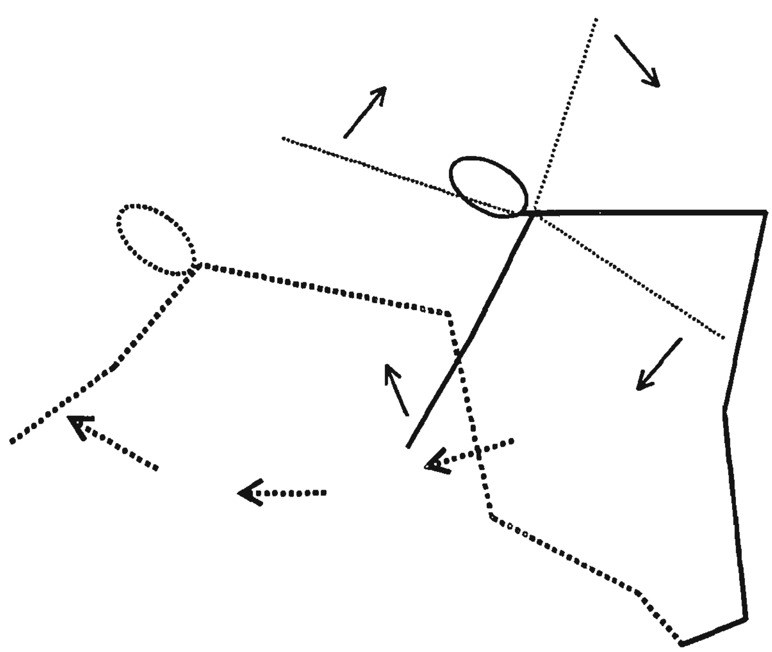


Figure 4.3: The swing start

Testing protocols

Pre-testing and post-testing sessions consisted of 2 parts: (1) six dry-land tests of strength, power and jumping ability; and, (2) the performance of three dive start techniques. The dry-land and dive testing protocols were identical for both the pre-test and post-testing sessions. The dry-land pre-testing session was conducted seven days prior to the dive start tests. Dry-land post-testing was performed five days after the completion of the resistance training program and two days prior to dive start testing.

Immediately following the pre-test participants were informed of their random allocation to either a control (C) group (N=12) or resistance-training (RT) group (N=14). More participants were allocated to the RT group as the risk of dropout was deemed to be more likely from this group. The C group were instructed to continue with their normal daily routines whilst the RT group participated in a nine-week training program designed to enhance jumping ability. Throughout the course of the study, one participant withdrew from the C group (N=11) and two from the RT group (N=12) due to injury (non-study related) or time constraints.

Dry-land tests

Six tests of muscular function were used in this study, which included two vertical jumping tests, two overhead shot throws and two 1RM squat exercises. The tests and their abbreviations are listed below. The main quality assessed by each test is included in Table 4.2 in order to help justify the inclusion of the six tests.

(1) Countermovement jump, with arm swing (VJ)

(2) Countermovement jump, without arm swing (CMJ)

(3) Seated overhead shot throw, without back extension (OT)

(4) Seated overhead shot throw, with back extension (OTB)

(5) CES concentric squat, bar speed of 40^0/s (SQ40)

(6) CES concentric squat, bar speed of 25^0/s (SQ25)

Table 4.2: Dry-land Tests and the Quality Assessed

TEST	QUALITY ASSESSED
VJ	Standing vertical jumping ability
CMJ	Leg extensor power, specific to standing vertical jump
OT	Shoulder power
OTB	Back extensor power and shoulder power
SQ40	Leg extensor power, no jumping skill required
SQ25	Leg extensor strength

In groups of four, participants performed the tests during an allotted time. Before each testing session each group performed a standardised warm-up. The aerobic warm-up consisted of 12 shuttle runs the length of the gymnasium (approximately 30m), touching the line at each end, in the order of four slow lengths, two at 50% effort, two at 75% effort, two slow, two of bounding and finally two very slow lengths. This was followed by static stretching of the hamstring, quadricep, calf, back extensor and posterior deltoid muscles.

Each group performed the tests in random order to counterbalance any possible ordering effects, such as learning and fatigue. Participants were coached before each of the six tests until they were confident and produced good, consistent techniques. Three minutes rest between each test was given. Three trials were performed for each test, with 30 s rest between each trial. The best performance of the three trials was used for analysis.

(A) Vertical jumping tests:

The VJ is a commonly accepted test of power used by many researchers in swimming (Ballow, 1979; Breed, 1998; Counsilman & Counsilman, 1994; Rohrs et al., 1991). The VJ was selected in this study as a measure of jumping ability. A Yardstick, which is a stand with movable vanes at centimetre intervals (Swift Performance Equipment, Australia), was used to measure the height of jump for the VJ to the nearest centimetre. The participants' standing height was measured on the Yardstick by fully extending the body with the preferred arm raised above the head, non-preferred arm by the side and feet together with heels on the floor (see Figure 4.4). The VJ involved a standing double foot take-off with unlimited countermovement and arm swing. During the warm-up jumps, participants were coached to find the most appropriate range of movement and encourage a rapid speed of stretch-shortening of the leg extensors. Participants were instructed to jump explosively for maximum height to reach and knock the Yardstick vanes at the highest possible point of their jump (see Figure 4.5). The displaced vanes were not replaced between trials in order to give participants a target for motivation. The jump height was calculated by measuring the distance from the standing reach height to the final height.

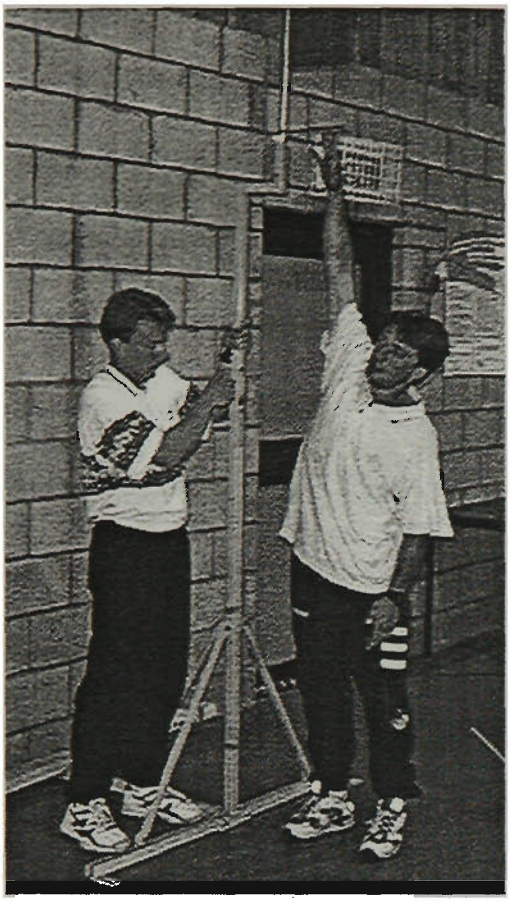


Figure 4.4: Zeroing the yardstick

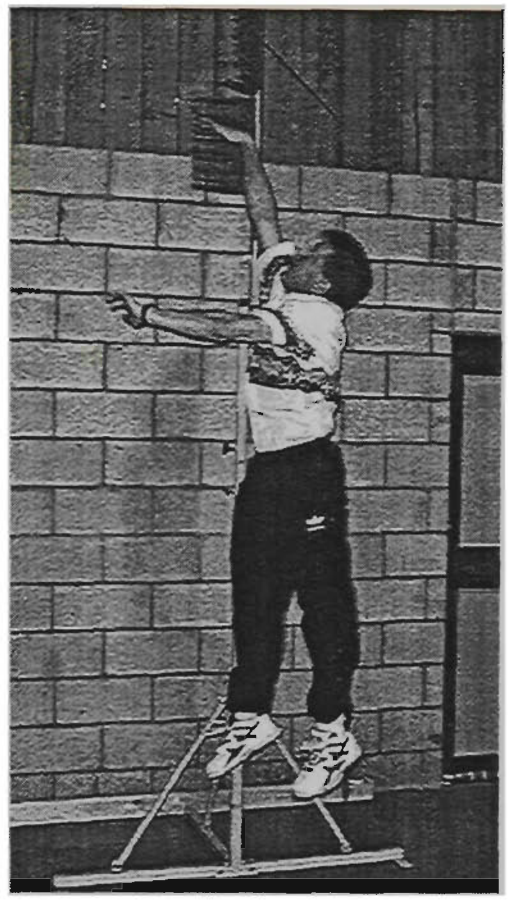


Figure 4.5: Displacing vanes during the VJ

For the CMJ test, participants stood on a 78 x 52cm contact mat (Young, Pryor & Wilson, 1995) with hands on hips. The contact mat was linked to a laptop computer so that the height data could be recorded and calculated. When ready, participants dipped down (countermovement) and then jumped up immediately by extending the legs and feet, ensuring that the hands remained on the hips at all times (see Figure 4.6). During the warm-up jumps, participants were coached to ensure an efficient use of the back and leg extensors (appropriate hip and knee flexion) and that the heels remained on the floor during the preparation phase of the jump (see Figure 4.6). On landing, participants were instructed to be in the same body position as during take-off (i.e. hip, knees and ankles in an extended position) to reduce the variation associated with the time spent in the air. If this position was not achieved then participants repeated the trial after the required rest period.

The software calculated jump height (rise of height of CG) from the flight time, based on the formula of $g.t^2/8$ (Bosco et al., 1983). This formula assumes that the height of the CG at landing is the same as during take-off. Therefore, the hands must remain fixed on the hips throughout the entire jump and the body should land in an extended position.

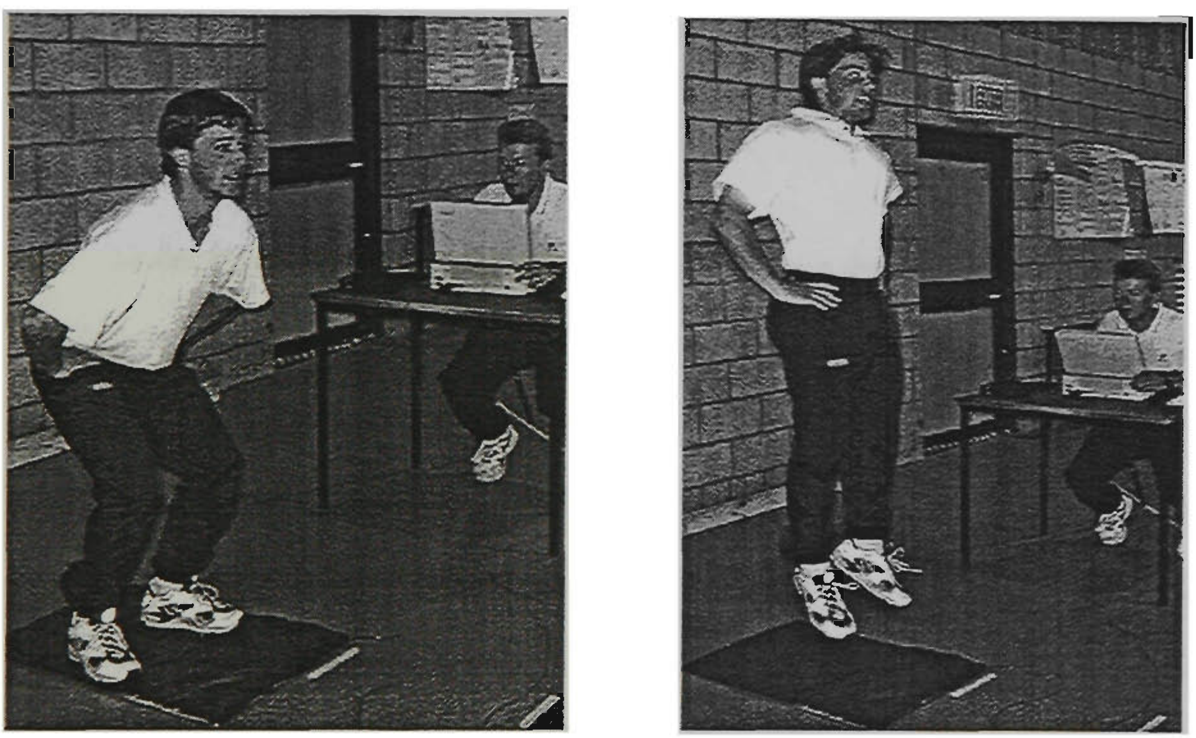


Figure 4.6: The CMJ

(B) Seated overhead shot throws:

A 6lb metal shot was used for both tests (OT and OTB). The shot was thrown onto two 13m long gymnastic tumbling mats (Acromat) placed side by side. Before each throw the shot was covered in magnesium chalk powder to enable the landing to be seen easily. Using a tape measure, the distance was calculated by measuring from between the back chair legs to the nearest chalk mark made by the shot on landing. The reading was rounded down to the nearest whole centimetre.

For the OT test, participants sat in a chair with their back facing the direction of the throw. The participants' heels were placed against the front legs of the chair with their back pressed against the chair upright. Participants were instructed to hold the shot with both hands, beginning with the arms extended and forearms resting on their thighs (see Figure 4.7). When ready, participants were instructed to throw the shot over their head for maximum distance whilst keeping their arms straight. The back was required to be pressed against the chair throughout the throw, with no countermovement of the shoulders or trunk allowed. If there was any countermovement then the trial was repeated. This was necessary in order to isolate and assess concentric shoulder muscle function.

In the OTB test, the participants began by sitting in the chair with heels against the chair legs and their back facing the direction of the throw. Holding the shot in both hands, the participant leaned forward until the hands were resting on the ground between the feet and in line with the toes (see Figure 4.8). When ready, the participant was instructed to throw the shot over their head for maximum distance by explosively extending the back and keeping the arms straight. The trial was repeated if there was any initial countermovement of the back or shoulders. Two spotters were used to hold the back upright of the chair to ensure that no tipping occurred in the follow through during both the OT and OTB tests.

Figure 4.7: The OT test

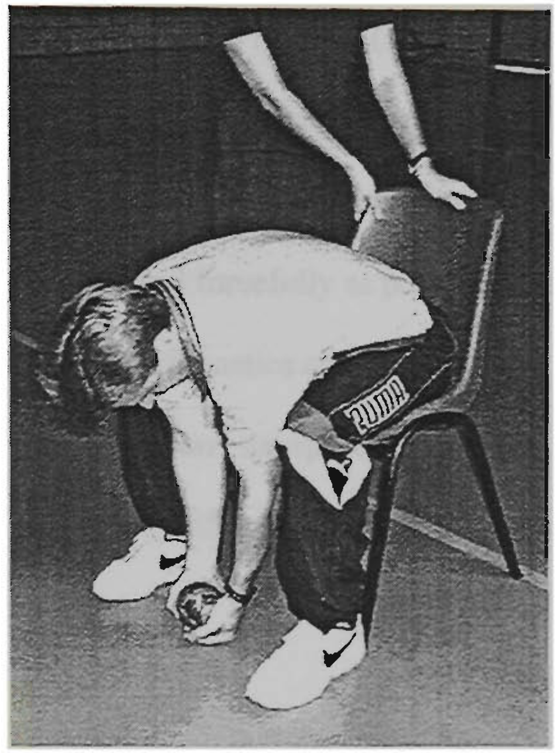


Figure 4.8: The OTB test

(C) Squat performance tests:

An Ariel 5000 Computerised Exercise System (CES) was used to assess the combined concentric muscular strength and power of the hip and knee extensors during a squat exercise. Peak strength was measured at an angular velocity of 25^0/s and peak power was measured at a velocity of 40^0/s (Ashley & Weiss, 1994). The force was calibrated dynamically prior to both testing sessions using 20 and 40kg Cybex weights.

The participants positioned their shoulders directly under the apex of the shoulder pads with the whole body in a vertical plane. The hands rested comfortably on top of the bar. A manual goniometer was used to determine a 90^0 range of motion for each participant before the tests. The range of motion was found by squatting down slowly until 90^0 was reached at the knee joint and then fully extending the legs to complete the whole movement.

Participants began from a standing position. On an audible signal from the CES, participants dipped down slowly whilst keeping the trunk vertical until another audible signal was heard, representing that 90^0 knee flexion had been reached (see Figure 4.9). In order to make the test one of purely concentric muscle function, the participants were instructed to hold this squat position for about 1½ seconds. Participants then reacted to a verbal 'go' signal by exploding upwards as quickly and forcefully as possible. Before each test (SQ25 and SQ40) participants had a number of practice trials (at 50-75% effort) to familiarise themselves with both the technique and the speed of bar movement. The CES bar was set at angular velocities of 25^0/s and 40^0/s for the two tests (SQ25 and SQ40).

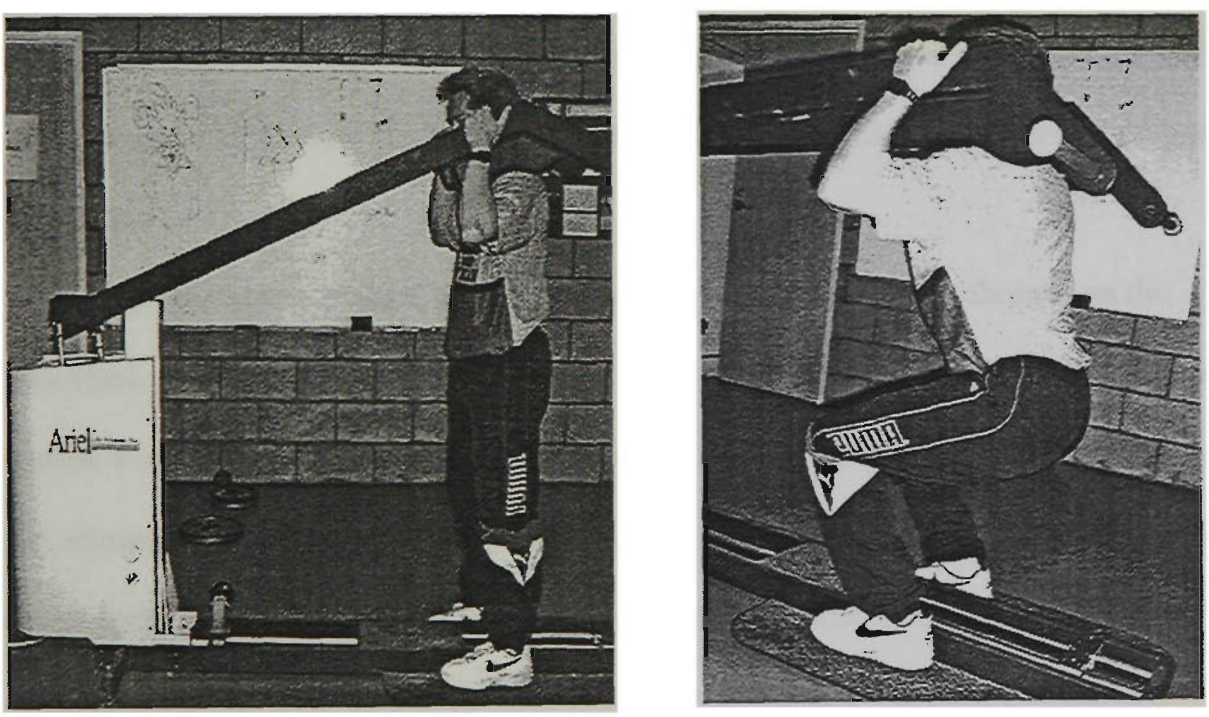


Figure 4.9: <u>Squat performance using the CES</u>

Swimming tests

The testing sessions were conducted at the University of Ballarat aquatic research centre in a heated indoor 25m swimming pool. Participants were randomly assigned to one of three groups for testing purposes only. Each group completed the testing session approximately 15 minutes before the commencement of the next group. Prior to a warm-up in the pool the participants had their height and mass measured. Ten anatomical points (see Table 4.4) were marked on each participant with a black water-resistant marking pen, with one further point (external auditory meatus) represented by wearing a yellow swimming cap with black markings (see Figure 4.2). This was to facilitate later digitising. The warm-up included five minutes of light swimming followed by three practice trials, performed at a maximal effort under race conditions for each of the diving techniques. During the practice, participants were required to try each dive technique from the modified starting block to familiarise themselves with it before the testing began.

In random order, participants performed two trials of each technique on the modified starting block and force platform. One trial was performed by each participant before a second trial was attempted, in the same random dive order. This allowed about six minutes rest between each trial, ensuring that fatigue did not affect the results. The commands as used in competitive racing starts applied. If participants false-started (as judged by the starter or an official viewing the monitor) they repeated the trial after a sufficient rest period.

Dive start instrumentation

Modified starting block

A 0.6 x 0.4m waterproof Kistler force plate (model 9253A11) was mounted on a modified steel starting block to measure the propulsive forces of the feet and the time during the block phase. The modified block was made from 3½ inch hollow square-section stainless-steel tubing. Cross struts were welded into the block for added strength and reduce the possibility of torsion affecting the readings from the force plate. The modified block was bolted into lane four of the pool deck in place of the original block (see Figure 4.10). The front edge of the block was a height of 0.62m above the water with the force plate set at an angle of 9^0 in compliance with FINA (1998) laws. The full dimensions of the modified block can be found in Appendix D.

Hand bar and frame

A steel frame constructed from 3½ inch hollow square-section steel was bolted separately from the modified block into the pool deck. Four holes were drilled and metal sleeves fitted into the concrete deck to allow the frame to be firmly bolted down. The rectangular base of the frame measured 112cm by 63cm. Rectangular uprights with solid steel brackets were welded to the base on either side of the block (see Figure 4.10). The full dimensions of the frame can be found in Appendix D.

At the front of the frame, a stainless-steel "L" shaped bar was fixed to allow the hands to grasp it during the grab and track starts. Left and right load cells were bolted to the brackets on the frame to measure the amount of strain and time of force application applied by the hands to the bar. The hand bar was welded to two universal joints (100kg maximal force) which were bolted to each load cell (see Figure 4.11).

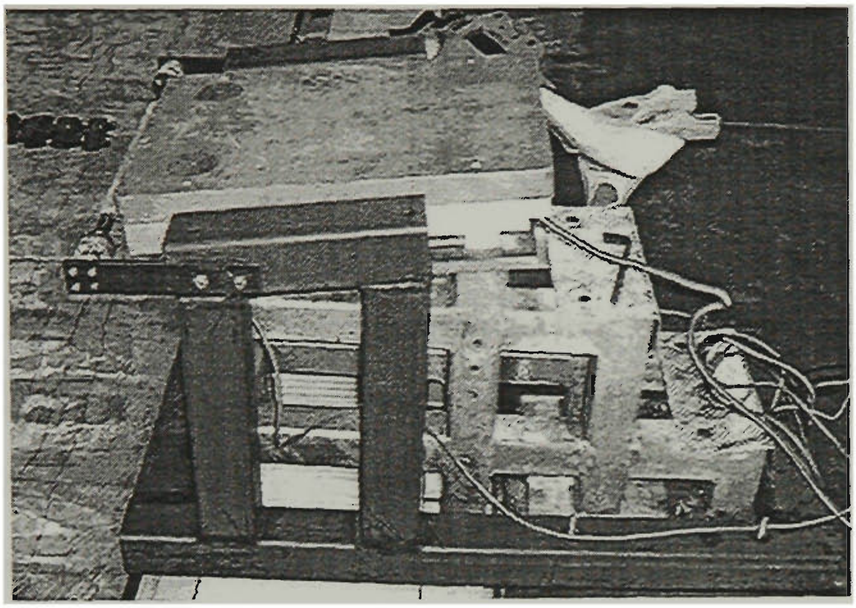


Figure 4.10: Modified starting block

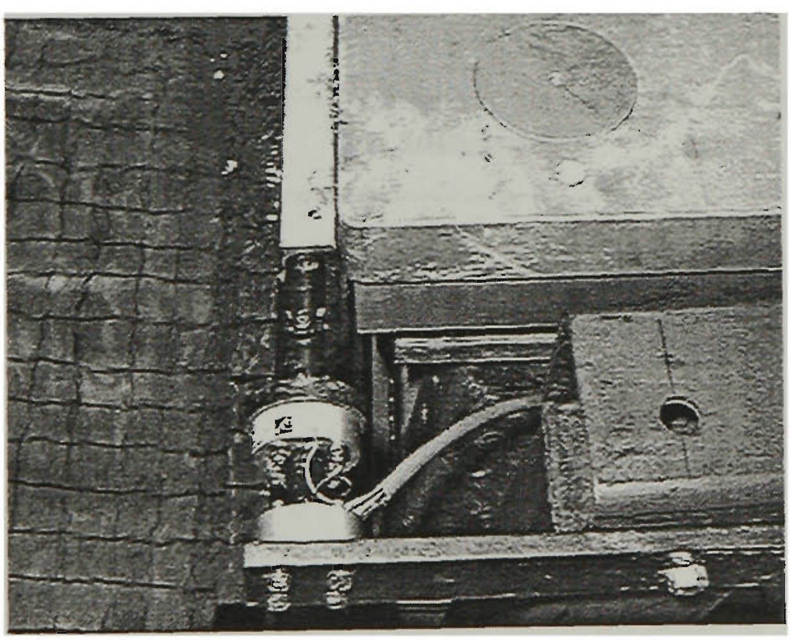


Figure 4.11: Hand bar set-up

The hand bar measured 500mm x 20mm x 20mm. The top of the bar was mounted 25mm below the front edge of the force platform to allow the distal joints of the toes to curl over the edge without influencing the force readings from the hand bar. Before each trial the researcher checked that the toes were not touching the hand bar. A 3mm gap was provided between the hand bar and the force plate so that the slight bending of the bar during the arm pull would not influence the force plate readings.

Force acquisition

Prior to the pre and post-testing sessions the force plate was calibrated by using 15kg and 30kg Cybex weights. The force plate and load cells sampled at a rate of 2000 Hertz. A Kistler eight-channel amplifier collected the analog signals from the force plate and load cells (see Table 4.3) which were then converted to digital data using an AP30 A/D module.

Table 4.3: Force Acquisition Channel Set-up

Channel		Instrument	Measurement
1	F_Y	Force plate	Horizontal (sagittal) plane
2	F_Z	Force plate	Vertical plane
3		-----------	
4		Starting horn signal	
5	F_Y	Left load cell	Hand bar horizontal force [a]
6	F_Z	Left load cell	Hand bar vertical force [b]
7	F_Y	Right load cell	Hand bar horizontal force [a]
8	F_Z	Right load cell	Hand bar vertical force [b]

([a] Channel 5 and 7 values were added to give total horizontal hand values)
([b] Channel 6 and 8 values were added to give total vertical hand values)

This information was saved via AP30 software (A. Pearce, University of Western Australia). Lateral forces (F_x) were not measured, as they were not deemed to be important for the purpose of this study. A starting horn was linked to a channel of the amplifier. The horn sent an electrical charge, which triggered the AP30 computer system to begin collecting force data for a period of 2 seconds. Force and time data for each channel was represented in graphical form and saved to file to be used for later analysis.

Video data collection

One Panasonic MS-5 VHS camera sampling at 50 Hz was used in this study. A shutter speed of 1/250th second was selected, with extra light being provided by a 2500 watt cinema light. The camera was positioned perpendicular to the plane of the dive, approximately 10m away (see Figure 4.12). The camera was connected to a timing box (For-A video timer) which allowed the image and time code (every 0.02 s) to be recorded onto a SVHS tape using a Panasonic SVHS video recorder (model AG7350). The timing box was activated by the starting signal and was reset to zero before each trial. A schematic diagram of the measuring system can be seen in Figure 4.13.

An above-water reference structure with the dimensions of 2m x 1m x 1m was positioned 1m away from the edge of the starting block to allow calculations of spatial coordinates to be made (see Appendix E). As 2-D analysis was used in the study, the side of the reference structure nearest the camera was aligned with the Y-axis of the block (plane of the dive). The structure was filmed immediately prior to the first trial and then removed from the pool. This enabled the velocity of take-off and joint positions throughout the dive to be calculated later using the Ariel Performance Analysis System (APAS).

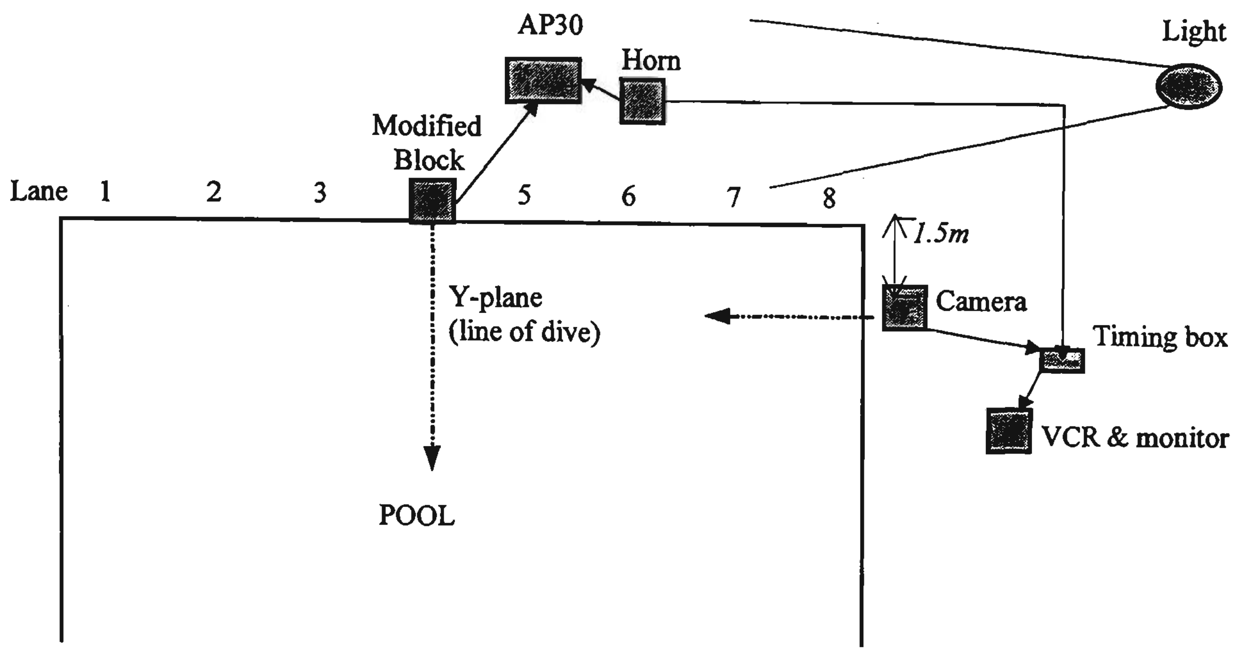


Figure 4.12: Equipment layout

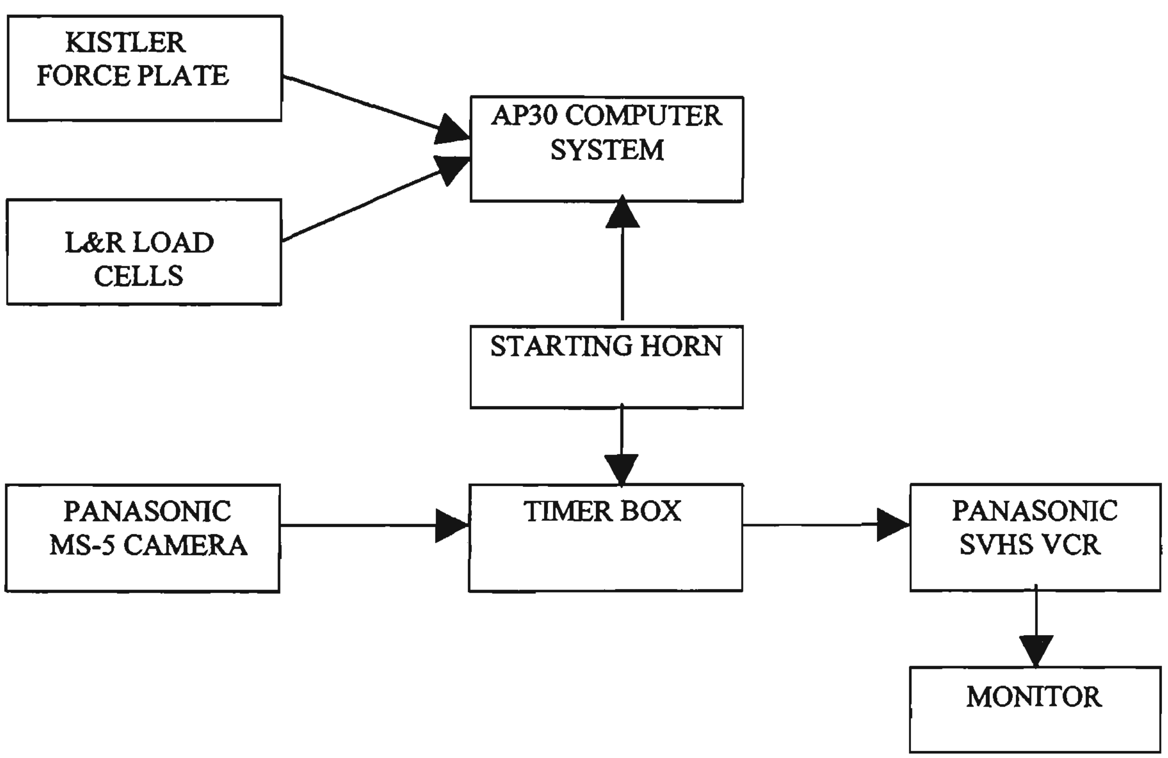


Figure 4.13: A schematic model of the dive start measuring system

Video Analysis

Temporal and kinematic dive start variables were obtained directly from the video tape. The time code for BT was taken from the first field in which the feet had left the block and, for FT, the first field that the fingertips entered the water. Block time and FT were combined to give the TT to water entry. Therefore, the times were accurate to 0.02 second. Two-dimensional video was used for analysis of the three dive techniques. An APAS (Windows 95) was used to digitise eight points of the body for the grab and swing starts and eleven points for the track start (see Table 4.4).

Table 4.4: Anatomical Landmarks used for Digitising

Landmark	Location (joint)	Segment
1	Distal end of the fifth metatarsal. Lateral side	------
2	Lateral malleolus of the fibula (ankle)	Left foot
3	Lateral epicondyle of the femur (knee)	Left lower leg
4	Greater trochanter (hip)	Left shank
5	Lateral greater tubercle of the humerus (shoulder)	Trunk
6	External auditory meatus (ear)	Head/neck
7	Lateral epicondyle of the humerus (elbow)	Left upper arm
8	Styloid process of the ulna (wrist)	Left forearm
9*	Distal end of the first metatarsal. Medial side	------
10*	Medial malleolus of the fibula (ankle)	Right foot
11*	Medial epicondyle of the femur (knee)	Right lower leg
		Right shank

* Extra digitising points for the track start.

Segmental models for each start can be found in Figures 4.14 and 4.15. The body's CG was calculated from the CM of these segments. A scale provided by the reference structure enabled the raw joint positions, displacement and velocity of the CG to be measured. Once the digitising process for the participant was completed the data was transformed using the DLT method and each joint was smoothed using a cubic spline algorithm, which is recommended for data smoothing of projectile motion (McLaughlin et al., 1977). This allowed higher noise frequencies, such as digitising error, to be filtered out.

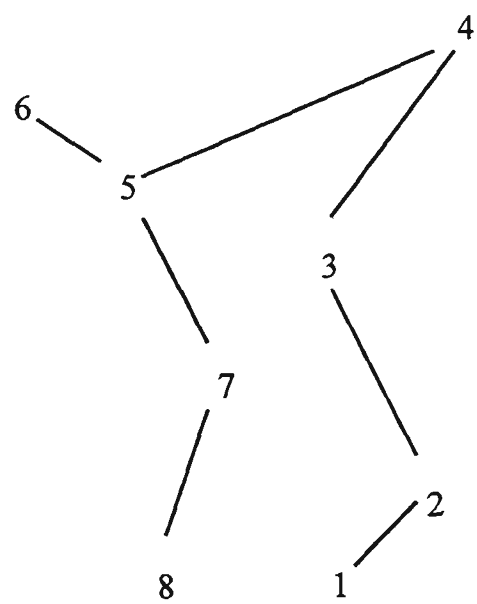


Figure 4.14: Segmental model for the grab and swing starts

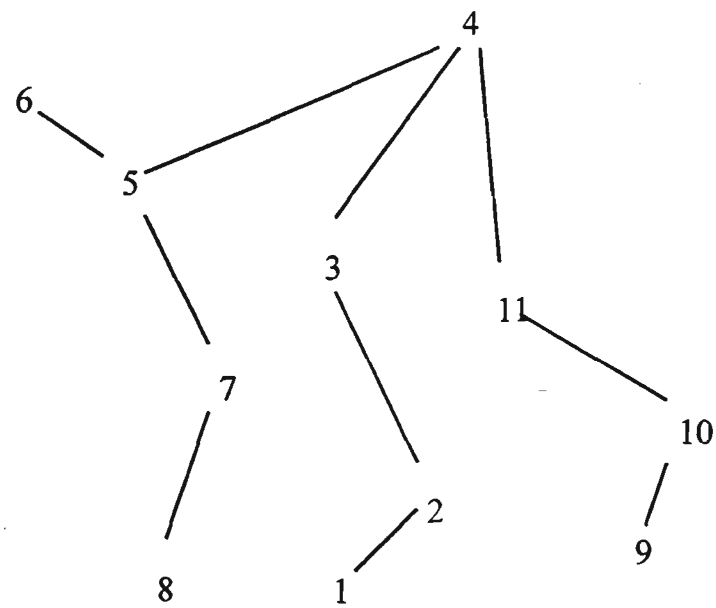


Figure 4.15: Segmental model for the track start

Force analysis

AP30 software was used to calculate the force and impulse. Force-time curves of the seven channels were displayed graphically. The data was smoothed using a fourth order Butterworth filter set at a frequency of 10 Hertz. Force readings of each channel were taken from the starting signal until the point at which the line graph crosses the zero mark, representing the point where the feet have cleared the block or the hands have cleared the strain bar. The AP30 software calculated the time between these two points, the area under the curve, peak forces and average forces in the Y and Z directions. Lateral (X-axis) forces were not measured as they were deemed to be unimportant for the purpose of the study. As the starting block had a downward slope of 9^0, results were adjusted using trigonometry to give true horizontal and vertical force components. The following equations (Jeurgens, 1994) were used:

$$F_Y' = F_Y \cos\theta + F_Z \sin\theta$$

$$F_Z' = -F_Y \sin\theta + F_Z \cos\theta$$

where θ was equal to 9^0 and F_Y and F_Z were the respective forces acting in a parallel and perpendicular direction to the block surface. $F_Y{}^{/}$ was the adjusted force parallel to the pool deck and $F_Z{}^{/}$ was the adjusted force perpendicular to the pool deck (see Appendix F). The left and right load cell readings were added to give total forces for the horizontal and vertical directions of the hand pull.

Resistance training

Initially, fourteen participants were randomly selected to perform resistance training for a period of nine weeks, with a two-week maintenance program over a semester holiday break. All of the participants had some experience and knowledge in resistance training, but no participant had previously used strength training programs specific to their chosen sport. Three training sessions per week were performed by the RT group. If a participant missed more than five sessions over the nine-week training period, they were excluded from the analysis (N=2).

The main purpose of the program was to enhance vertical jumping performance. The program was periodised to initially improve strength and power, mainly through traditional weight-training exercises. The main muscle groups used in vertical jumping were trained, which included the leg extensors, lower trunk and shoulders (Khalid et al., 1989; Luhtanen & Komi, 1978). More specific exercises for vertical jumping were included in the latter part of the program, with maintenance of general lower and upper body strength and power. A combination of weight training methods and plyometric jumping exercises have repeatedly been shown to be successful in improving vertical jumping ability (Adams et al., 1992; Bauer et al., 1990; Clutch et al., 1983; Lyttle et al., 1996). The program is shown in Table 4.5. Detailed explanations of the exercises can be found in Appendix G.

Table 4.5: Nine-week Resistance Training Program

WEEK 1-3			
Session 1 & 3		*Session 2*	
Clean pull	4 x 5 (8RM)	Barbell jump squat	5 x 5 (25-35 lb)
Barbell press (behind neck)	3 x 8 (10RM)	Back extension	3 x 10-15
Parallel squat (Smith machine)	3 x 8 (10RM)	Prone hold	3 x 20-30 secs
Back extension	3 x 10-15		
Prone hold	3 x 20-30 secs		
WEEK 4-6			
Session 1 & 3		*Session 2*	
Barbell jump squat	4 x 4 (35-45 lb)	Weighted belt jumps	5 x 5 (20 lb)
Dumbbell overhead press	4 x 6 (6RM)	Back extension	2 x 8 (5-10 kg)
Barbell ½ squat	4 x 6 (6RM)	Twisting crunch	2 x max.
Back extension	2 x 8 (5-10 kg)		
Twisting crunch	2 x max.		
HOLIDAY BREAK (2 WEEK MAINTENANCE)			
WEEK 1 (3 sessions)		*WEEK 2 (3 sessions)*	
Drop jump	4 x 5 (35-40 cm)	Drop jump	5 x 5 (40-50 cm)
Explosive push-up	4 x max.	Explosive push-up	4 x max.
WEEK 7-8			
Session 1 & 3		*Session 2*	
Drop jump	5 x 5 (50-60 cm)	Barbell ½ squat	4 x 5 (5RM)
Forward pulley thrust	5 x 5 (8 RM)	Barbell jump squat	4 x 5 (35-45 lb)
Weighted belt jump	5 x 5 (20-30 lb)		
Incline shoulder raise	5 x 5 (5 RM)		
Side hold	3 x 20-30 secs		
WEEK 9 (TAPER)			
Session 1 & 3		*Session 2*	
Drop jump	3 x 5 (50-60 cm)	Barbell ½ squat	3 x 5 (5 RM)
Forward pulley thrust	3 x 5 (8 RM)	Barbell jump squat	3 x 5 (35-45 lb)
Weighted belt jump	3 x 5 (20-30 lb)		
Incline shoulder raise	3 x 5 (5 RM)		
Side hold	2 x 20-30 secs		

Prior to the commencement of the training program participants had two familiarisation sessions in the gym to practice and learn the correct techniques of the exercises. During these sessions the starting weights for the exercises were found for each participant. At least two of the three training sessions a week that the participants attended were required to be supervised sessions. This enabled their progress and the program to be followed closely. Participants were required to fill out the details for each completed session of their program.

Each training session began with participants performing a 5-10 minute aerobic warm-up on a bicycle ergometer, stepper or treadmill. Before each resistance exercise, the participants performed two warm-up sets slowly and with light weights (approximately half the starting weight of the first set). All of the exercises, other than those targeting abdominal and back extensor muscles, were performed with an explosive upward phase of the lift. Participants were instructed to have complete rests between sets.

Treatment of data

An SPSS (version 7.5) statistical package was used for all analyses in this study. In the comparison of the three dive techniques, a criterion distance including an underwater phase of the start was not used (eg. dive time to 7m) due to the inexperienced nature of the sample group. Hence each measure of dive performance was treated as a separate dependent variable. Means and standard deviations were calculated for all variables. A univariate analysis of variance test was conducted in order to compare the three starts in nine selected dependent variables. Variables measured by the load cells were only common to the grab and track start and, therefore, were not included in the three-way comparison of the techniques.

In part two of the study, a repeated measures multiple analysis of variance (MANOVA) test was conducted to find out if there was a training effect across all six dry-land tests. The MANOVA was a 2 x 2 design, consisting of group (control/resistance-training) by time (pre/post-test), with six repeated measures of dry-land test results. Comparatively small participant numbers would have limited the usefulness of the MANOVA. Univariate analysis of variance (ANOVA) results were derived for each of the six dependent measures to find out which tests significantly improved by training.

Nine separate 2 x 2 (group by time) repeated measures MANOVA tests, one for each dependent variable used in part-one of the study, were conducted across each diving technique (within-subject factors of grab, track and swing). ANOVA results were derived for each starting technique to find out which technique was improved by training.

CHAPTER FIVE

RESULTS

The results of the current study, which aimed to identify the most effective starting technique and the effect of a resistance-training program on each start, are discussed in two parts. In part one, the pre-intervention data for all participants (N=23) was used for analysis. For part two of the study the participants were randomly selected into a control (C) or a resistance-training group (R), and were re-tested following the nine-week intervention of resistance training.

PART 1: A pre-intervention comparison of the three diving techniques.

Nine dive performance variables were selected for statistical analysis between the grab, track and swing starts. These variables included the block time (BT), flight time (FT), total time to entry (TT), flight distance (FD), resultant take-off velocity (V), take-off angle (TA), entry angle (EA), vertical impulse (VI) and total horizontal impulse (HI). Paired samples within each start were performed in order to compare the first and second trial across the nine variables. No significant differences between trials were found at a 99% level of confidence. Therefore, an average of the two trials for each variable was used for analysis. The results of the paired-samples test can be found in Appendix H.

No direct force measure of arm contribution could be measured for the swing start using the equipment available for this study. Therefore, kinetic measures provided by the arms were not included in a three-way statistical comparison of the techniques. However, means and standard deviations of selected measures obtained from the strain bar by the hands are included in Table 5.2 for a general comparison and later discussion of the grab and track techniques. Horizontal impulse was included for statistical comparison of the techniques, as it is an important variable contributing to velocity and flight distance (Bowers & Cavanagh, 1975; Hay & Guimaraes, 1983; Miller et al., 1984). Positive horizontal hand forces were added to the adjusted horizontal force plate readings as they were deemed to directly contribute to the body's horizontal momentum. This was not the same for vertical impulse, as the arms generally act to pre-tense the muscles and hence increase force production during starts involving a grasping of the block (Shierman, 1979; Pearson et al., 1998). Therefore, the vertical impulse of the feet was used for statistical comparison of the three starts.

The means and standard deviations within each start for selected temporal and kinematic variables are shown in Table 5.1, and selected kinetic variables are shown in Table 5.2. Vertical impulse of the feet is adjusted to allow for body mass.

Table 5.1: Summary of Selected Temporal and Kinematic Variables

	Grab start		Track start		Swing start	
Variable	Mean	SD	Mean	SD	Mean	SD
BT (s)	0.93	0.06	0.96	0.07	1.14	0.08
FT (s)	0.25	0.07	0.26	0.07	0.26	0.07
TT (s)	1.18	0.08	1.22	0.09	1.40	0.08
FD (m)	2.65	0.24	2.83	0.24	2.72	0.22
V (m/s)	3.14	0.26	3.44	0.26	3.17	0.26
TA (deg)	-6.7	7.3	-12.1	7.3	-8.1	7.1
EA (deg)	39.4	7.4	39.4	7.3	37.2	6.8

The swing start was considerably slower to enter the water than either the grab or track starts. As FT was similar for all three starts, this difference in TT was almost entirely due to the BT differences. The track start travelled the furthest in the air, mainly due to its faster take-off velocity. The EA was very similar for all three starts, whereas the track start had the flattest TA and the grab start the highest. The greatest spread of results (standard deviations) occurred with the angular kinematics.

Table 5.2: Summary of Selected Kinetic Variables

Variable	Grab start Mean	Grab start SD	Track start Mean	Track start SD	Swing start Mean	Swing start SD
HI (Ns)	180.8	15.8	199.7	30.8	197.0	21.4
HI, feet (Ns)	174.4	19.0	129.5	23.1	197.0	21.4
HI, hands (Ns)	6.4	10.9	70.2	27.4	- - -	
Total peak hor. force (N)	631.8	49.2	553.4	85.9	743.7	79.6
Peak hor. force, feet (N)	603.2	54.5	363.4	48.8	743.7	79.6
Peak hor. force, hands (N)	28.6	29.3	190.0	67.8	- - -	
VI (Ns)	58.8	33.1	79.2	30.9	103.1	21.3
VI, hands (Ns)	155.6	69.6	191.5	74.4	- - -	
Time of hand contact (s)	0.59	0.08	0.63	0.09	- - -	

When comparing the grab and track starts, the hand contribution of the track start is considerably greater, particularly in the horizontal direction. The HI of the track and swing start is similar. Figures 5.1, 5.2 and 5.3 show typical unadjusted force traces for each start technique. This allows visual comparison of the mechanisms involved in the starting performance of the three techniques. In all graphs, time point no.1 (X-axis) represents the starting signal. Each number on the time axis equals 0.5 ms (i.e. 1000 is equal to 500 ms or 0.5 s).

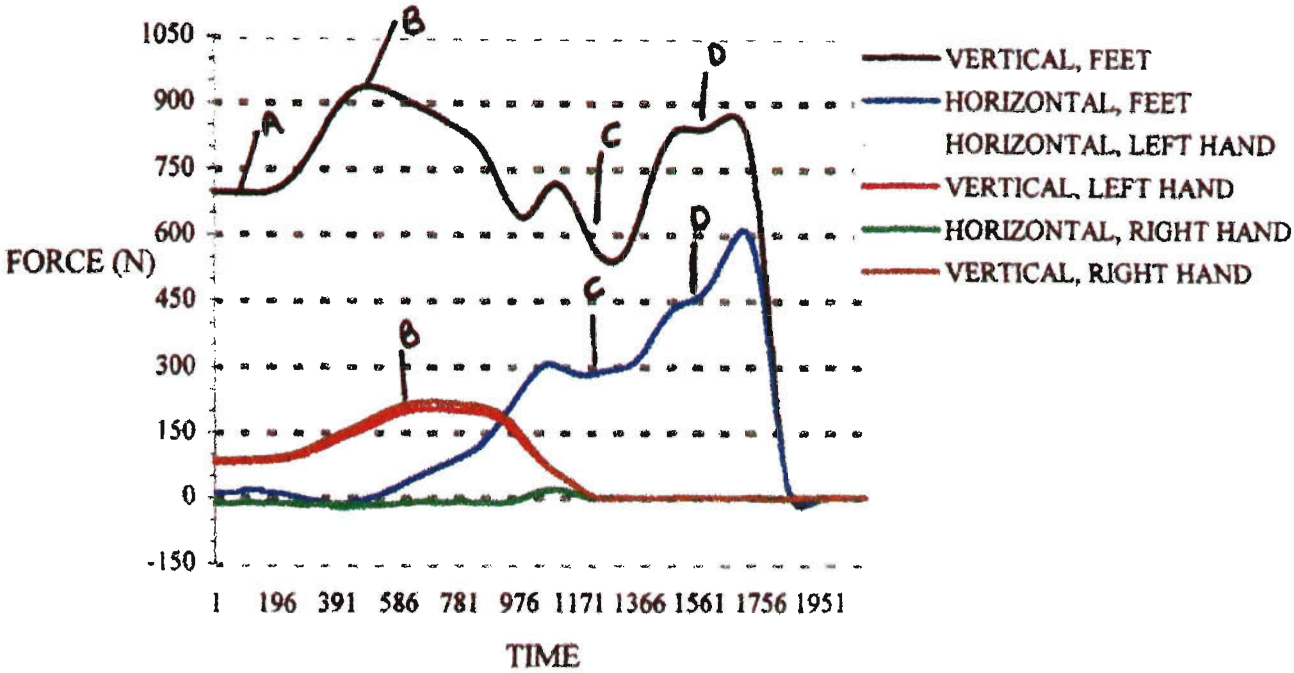


Figure 5.1: Typical force trace of the grab start

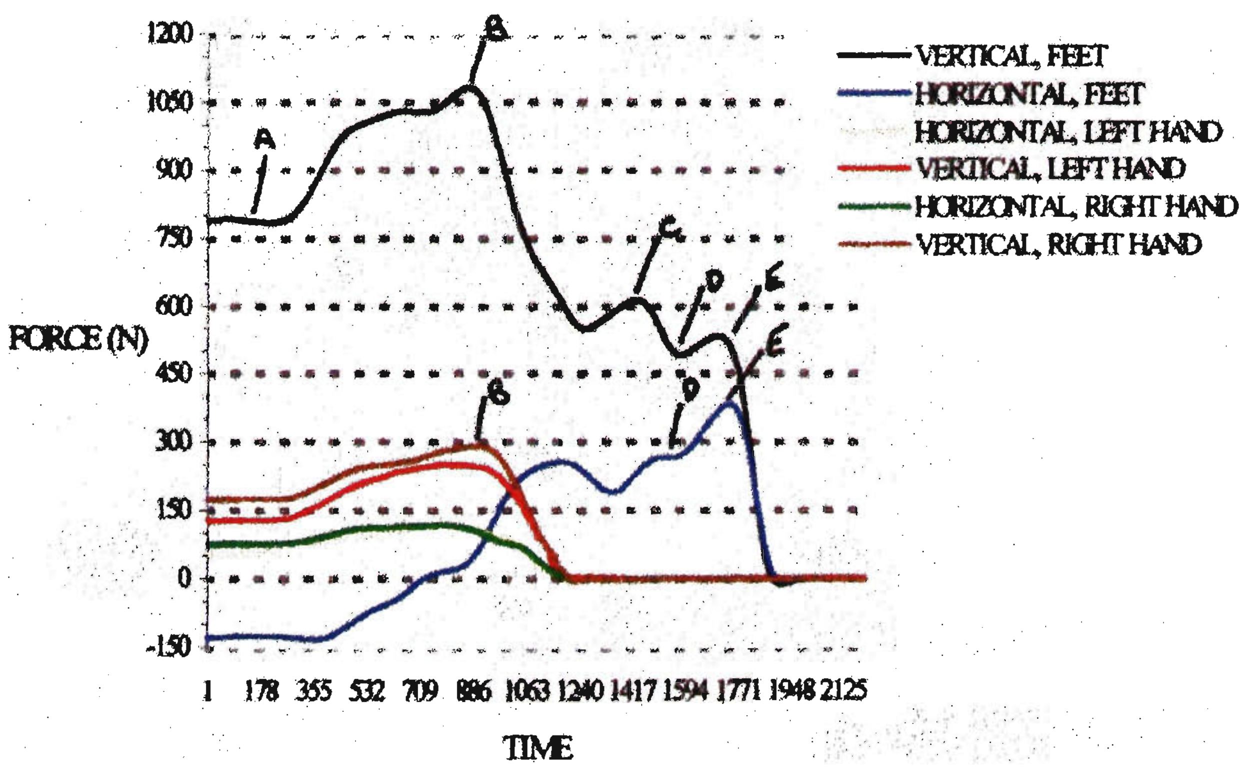


Figure 5.2: Typical force trace of the track start

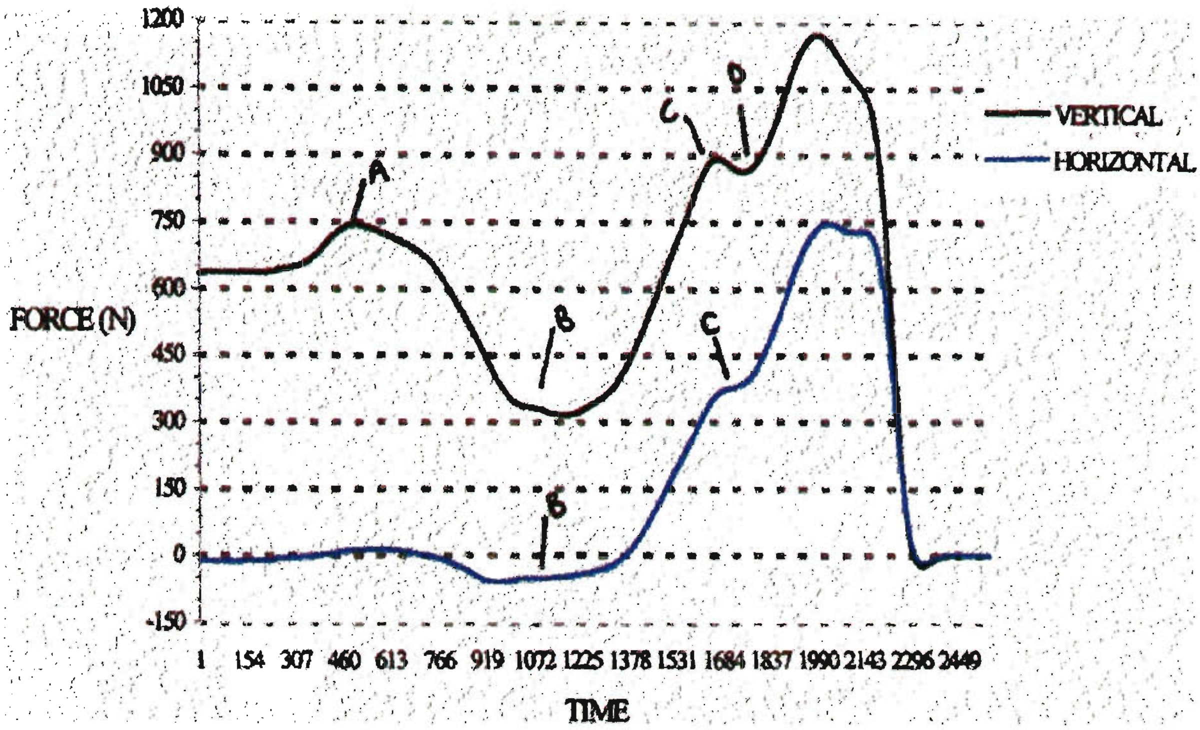


Figure 5.3: <u>Typical force trace of the swing start</u>

In the force trace of the grab start (see Figure 5.1), point-A represents the body's mass and the pre-tension of the legs. Vertical peaks of the hands and feet were reached shortly after the reaction to the starting stimulus (point-B). Vertical force traces of the hands and feet followed a similar pattern, although the magnitude of the hands was considerably less, as a greater force production of the arms contributed to increased pre-tension (and hence power output) of the legs. Horizontal force of the arms was negligible, with the magnitude depending on the amount of body lean of the participant prior to the start. Point-C represents a decrease in the vertical force of the feet as the body dropped downwards, corresponding with a decrease in arm contribution just prior to the hands leaving the block. A flattening of the horizontal force trace, along with this decrease in vertical force, was in part due to a switching of eccentric to concentric contraction of the leg extensor muscles, as the knee angle reached about 90^0 and the body moved into its line of push. Another smaller flattening out occurs (point-D) in the force traces just prior to the final peaks, caused mainly by the arms being swung upwards and forwards.

The pre-tension developed in the legs was greater in the track technique (see Figure 5.2) than in the grab technique (point-A). As in the grab start, the vertical force traces of the arms follow a similar pattern to the vertical force pattern of the feet. Although considerably less in magnitude (point-B), the arms were used in the vertical direction mainly to pre-tense the leg muscles and keep the body stable whilst in a low and backward position. An initial negative horizontal force of the feet is caused by the backward body position of the track start, which is overcome by the horizontal pulling of the arms to propel the body forwards. Shortly after the hands leave the bar, the rear-leg provides extra horizontal and vertical drive (point-C) just prior to leaving the block (point-D). Horizontal force increases as the front leg extends and has stronger joint positions for providing maximal drive (point-E).

In the swing start (see Figure 5.3) there is a slight increase in vertical and horizontal force as the participant reacts to the starting stimulus (point-A). Although less in magnitude, the horizontal force trace follows a very similar pattern to the vertical trace, unlike those of the grab and track starts. A large dip in the graph coincided with the arms being swung upwards, with the lowest point on the vertical line being when the hands, and hence CG, were at their highest point (point-B). The force production increased as the arms were swung downwards (point-C), with a small decrease in force as the arms were brought upwards and forwards (point-D) to be extended above the head in preparation for the maximal effort in the line of push.

Within each start technique homogeneity of variance P-P plots were performed for each variable. Further analysis using Levene's test of homogeneity of variance showed that all variables, other than horizontal impulse, met the assumptions required for more detailed analysis (see Appendix I). A univariate one-way ANOVA was performed to find if significant differences existed between each dive technique for the nine dependent variables (see Table 5.3).

Table 5.3: Univariate Analysis of Variance

Variable	df	MS	*F*	Sig of *F*
BT	3, 69	0.298	57.205	0.000[b]
FT	3, 69	0.001	0.254	0.777
TT	3, 69	0.320	43.249	0.000[b]
FD	3, 69	1723.691	3.323	0.042[a]
V	3, 69	5989.468	8.976	0.000[b]
TA	3, 69	179.468	3.411	0.039[a]
EA	3, 69	37.919	0.733	0.484
VI	3, 69	11312.344	13.562	0.000[b]
HI	3, 69	2402.378	4.351	0.017[a]

[a] $p < 0.05$ [b] $p < 0.001$

The results of the univariate ANOVA showed that significant differences ($p < .05$) existed between seven of the nine variables. Significant differences existed between the starting techniques for BT, TT, V and VI at the 99.9% level of confidence, and for FD, TA and HI at the 95% level of confidence.

A Tukey HSD post-hoc test was used for further analysis to show which of the diving techniques were significantly different within the significant variables (see Table 5.4). As the data for HI was not normally distributed, Tamhanes non-parametric post-hoc test was used for analysis of that variable (see Table 5.5).

Table 5.4: Tukey HSD Post-hoc Test for Significant Variables

Variable	Start type	Grab	Track	Swing
	Grab	-----	.297	.000[c]
BT	Track	.297	-----	.000[c]
	Swing	.000[c]	.000[c]	-----
	Grab	-----	.180	.000[c]
TT	Track	.180	-----	.000[c]
	Swing	.000[c]	.000[c]	-----
	Grab	-----	.021[a]	.521
FD	Track	.021[a]	-----	.229
	Swing	.521	.229	-----
	Grab	-----	.001[b]	.926
V	Track	.001[b]	-----	.003[b]
	Swing	.926	.003[b]	-----
	Grab	-----	.038[a]	.802
TA	Track	.038[a]	-----	.153
	Swing	.802	.153	-----
	Grab	-----	.050	.000[c]
VI	Track	.050	-----	.018[a]
	Swing	.000[c]	.018[a]	-----

[a] $p < 0.05$ [b] $p < 0.01$ [c] $p < 0.001$

The grab and track starts were significantly different for V at the 99% level of confidence, and for FD, TA and HI (see Table 5.5) at the 95% level. The grab and swing starts were significantly different for BT, TT and VI at the 99.9% level of confidence. The track and swing starts were significantly different for BT and TT at the 99.9% level of confidence, and for V and VI at the 95% level.

Table 5.5: Tamhanes Post-hoc Test for Horizontal Impulse

Variable	Start type	Grab	Track	Swing
	Grab	-----	.022[a]	.058
HI	Track	.022[a]	-----	.918
	Swing	.058	.918	-----

[a] $p < 0.05$

PART 2: The effect of resistance training on swimming starts

For part two of this study, participants were randomly selected to a control (C) group (N = 11) or a resistance-training (R) group (N = 12). The R group participated in a 9-week program designed to enhance jumping ability. Part two of this study set out primarily to address two questions. Firstly, did resistance training improve vertical jumping ability and other tests of muscle function? Secondly, did the diving performance of the three starting techniques improve due to training?

Normal P-P plots were performed for all sets of data, which were found to be normally distributed. Individual participant raw data for each dry-land test can be found in Appendix B. Levene's test of equality of variances was conducted on all pre and post test dry-land data, with the error variance of all dependent variables being equal across groups at a 99% level of confidence (see Appendix J). Table 5.6 shows the means and standard deviations for the C and R groups both pre and post-test. Significant results of the univariate repeated measures analysis of variance (ANOVA), for a group by time effect, are indicated in bold type. Results of the ANOVA test can be found in Appendix K. Time of testing was the within-subjects factor (time effect) and the group was the between-subjects factor (group effect).

Table 5.6: Dry-land Test Descriptive Data

		CONTROL		RESISTANCE	
		Mean	SD	Mean	SD
VJ	Pre	40.2	5.0	37.8	6.9
(cm)	Post	40.7	4.8	43.1	6.2
	Change	+1.2%	-----	**+12.3%***	-----
CMJ	Pre	26.7	3.9	27.3	4.8
(cm)	Post	26.9	2.8	30.6	4.7
	Change	+0.7%	-----	**+10.8%***	-----
SQ40	Pre	111.7	14.7	113.4	19.8
(kg)	Post	113.5	8.8	131.6	19.9
	Change	+1.6%	-----	**+13.8%****	-----
SQ25	Pre	126.9	17.3	136.2	26.9
(kg)	Post	130.4	14.7	148.2	22.2
	Change	+2.7%	-----	+8.1%	-----
OT	Pre	5.01	0.62	5.51	0.66
(m)	Post	5.07	0.66	5.68	0.74
	Change	+1.2%	-----	+3.0%	-----
OTB	Pre	7.61	1.29	8.33	1.21
(m)	Post	7.92	1.14	8.51	1.08
	Change	+3.9%	-----	+2.2%	-----

* $p < 0.001$ ** $p < 0.05$

Results of a repeated measures multivariate analysis of variance (MANOVA) showed that there was no between-subject group difference (F = 1.258, Sig of F = 0.330) for all tests. However, there was a significant time effect (F = 13.989, Sig of F = 0.000), indicating an improvement in results from pre to post test of both groups collectively. More importantly, a significant time by group effect was found (F = 10.245, Sig of F = 0.000), which was of primary interest to the first hypothesis of part two in this study. The significant result of the MANOVA indicated that the resistance training improved performance in the dry-land tests.

Significant improvements over time were found for both jumping tests (VJ and CMJ) and CES squat tests (SQ40 and SQ25), showing that both groups collectively increased in performance (see Appendix K). No significant differences were found over time or group by time for the OT or OTB tests. The SQ40 test of leg power showed the largest improvement due to resistance training. A group by time effect was found in the VJ, CMJ and SQ40 tests (see Table 5.6), whereby the R group improved in performance significantly more than the C group. Figures 5.4, 5.5 and 5.6 show the mean training effect for the significant group by time univariate ANOVA results.

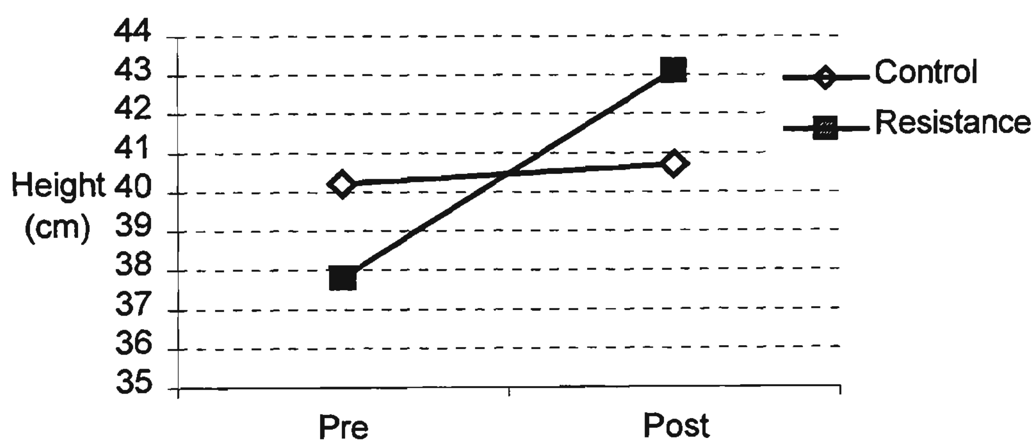


Figure 5.4: <u>Group by time effect for the VJ</u>

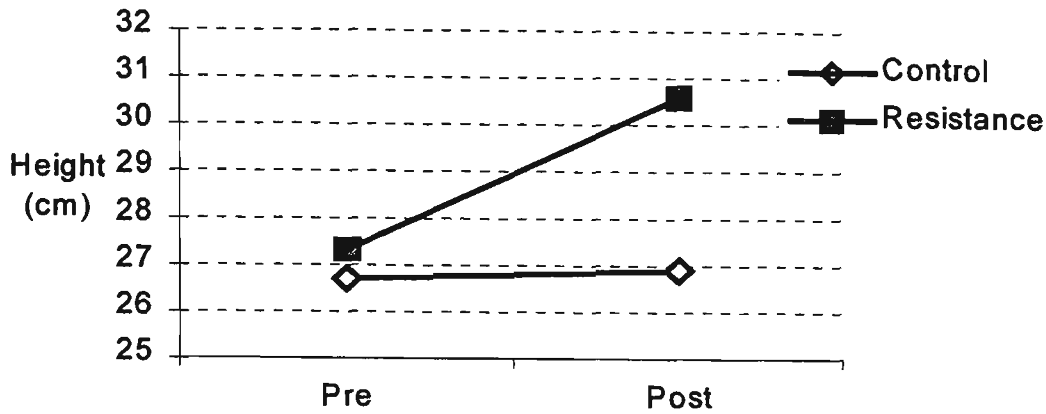


Figure 5.5: Group by time effect for the CMJ

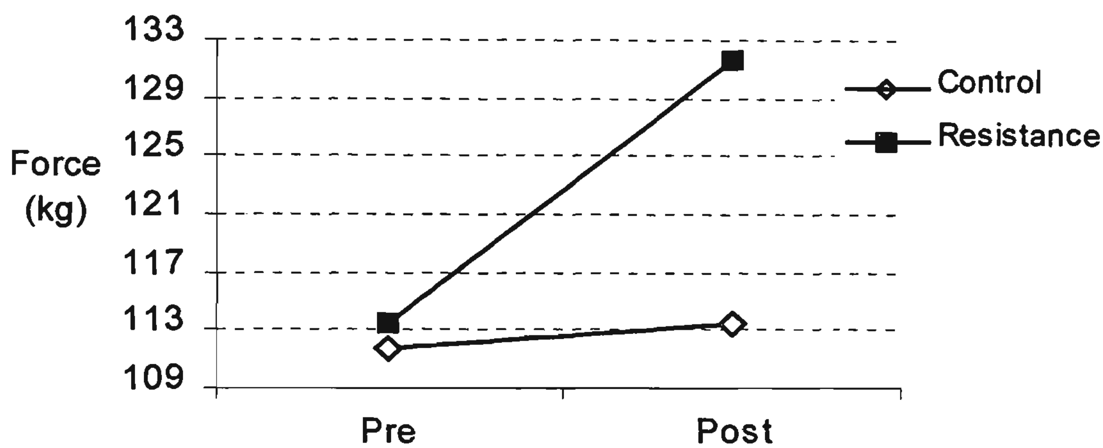
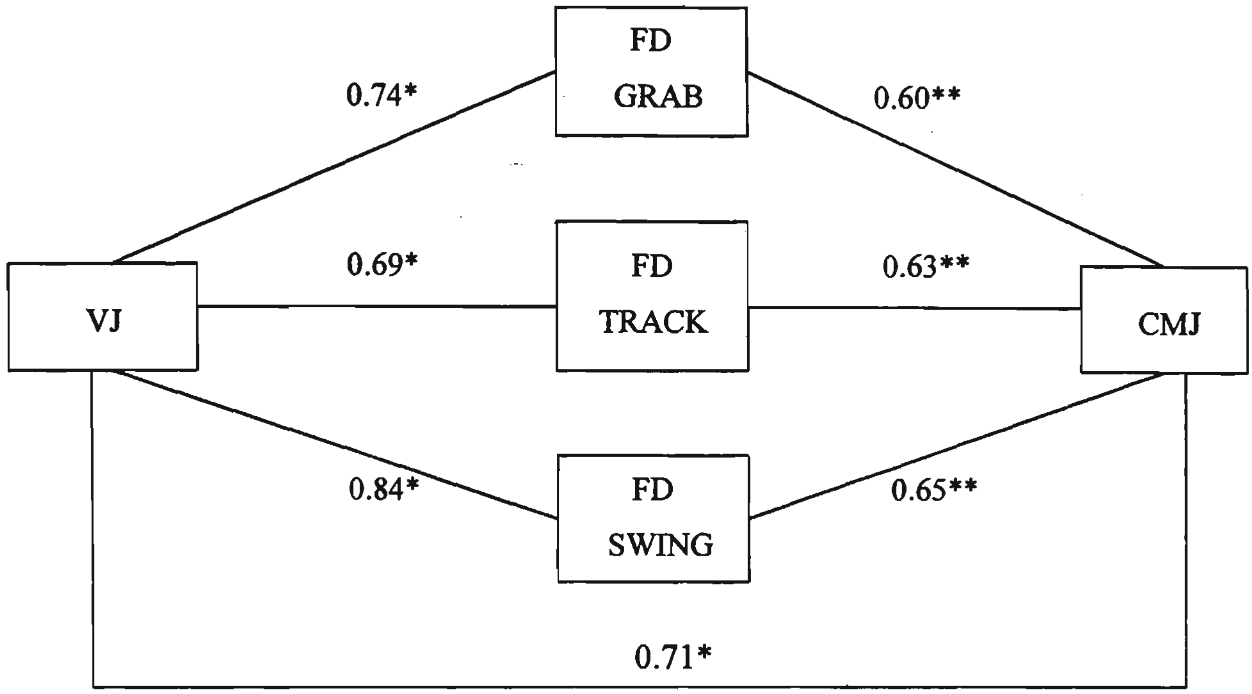


Figure 5.6: Group by time effect for SQ40

All of the above figures show a slight increase in mean performance by the C group over time (from pre to post-test). The steeper slope of the lines for the R group indicates much greater improvements in performance due to training.

A Pearson's bivariate correlation was performed on selected post-test variables to indicate what relationship existed between jumping ability and dive performance. Flight distance (FD) was used as a key indicator of dive performance. Figure 5.4 shows the correlation values between the VJ, CMJ and FD of all three diving techniques.



* p < 0.001 ** p < 0.01

Figure 5.7: Relationship between jumping tests and flight distance

The FD of all three dives were significantly correlated with both jumping tests – the VJ as a measure of jumping ability, and the CMJ as a measure of leg power in jumping. The VJ was more highly correlated with all three dives than the CMJ test. One further pattern that arose was that the swing start had the highest correlation with both jumping tests.

Nine separate repeated measures MANOVA tests for each dive start variable (BT, FT, TT, FD, V, TA, EA, HI and VI) were performed across the three techniques (repeated measures), with time of testing being the within-subjects factor and group being the between-subjects factor. Three further repeated measures MANOVA tests were performed across the grab and track starts for the kinetic variables of horizontal impulse of the feet (HIF), horizontal impulse of the hands (HIH) and vertical impulse of the hands (VIH). This was done to compare any changes in arm contribution to impulse due to training. The MANOVA results can be found in Appendix M. Results indicated no significant differences between groups for any variable ($p > 0.05$) across the three starts. Significant time effects ($p < 0.05$) were found within FT, TA, HI, VI, HIF, HIH and VIH. This indicated a change in results from pre to post test of both groups collectively. Of primary interest to the research hypotheses, group by time effects ($p < 0.05$) were found for TA, HI and HIH.

The means and standard deviations for all dive starts by group are shown in Tables 5.7, 5.8 and 5.9 as kinematic, temporal and kinetic descriptive data, respectively. Significant results for the group by time effects of the univariate repeated measures ANOVA are indicated in bold type. Univariate results were used as follow up tests for the main effect. All of the descriptive data by group and time and, complete ANOVA results by variable, can be found in Appendix N. Normal P-P plots indicated that data for each variable were normally distributed. Levene's test for homogeneity of variances showed that all dependent variables had equal variance across the three starts at a 99% level of confidence (see Appendix L).

Univariate results from the kinematic data revealed significant group by time differences for the track start in V and TA (see Table 5.7). No significant group by time differences were found for any other variable within the grab or swing starts ($p > 0.05$). However, within V and FD the group by time effect of the swing and track starts showed considerably greater improvements than in the grab start.

Table 5.7: Dive Start Descriptive Data for Kinematic Variables

FLIGHT DISTANCE		Mean	SD	Mean	SD
		CONTROL		RESISTANCE	
GRAB	Pre	2.64	0.24	2.65	0.24
	Post	2.66	0.21	2.65	0.35
	Change	+0.8%	---	0.00	---
TRACK	Pre	2.86	0.18	2.80	0.28
	Post	2.82	0.23	2.85	0.31
	Change	-1.4%	---	+1.8%	---
SWING	Pre	2.73	0.18	2.71	0.24
	Post	2.74	0.22	2.78	0.33
	Change	+0.4%	---	+2.6%	---
VELOCITY		Mean	SD	Mean	SD
GRAB	Pre	3.16	0.30	3.13	0.23
	Post	3.07	0.26	3.16	0.34
	Change	-2.9%	---	+0.9%	---
TRACK	Pre	3.46	0.28	3.42	0.25
	Post	3.33	0.30	3.48	0.26
	Change	-3.9%	---	**+1.7%***	---
SWING	Pre	3.12	0.33	3.21	0.18
	Post	3.11	0.36	3.34	0.35
	Change	-0.3%	---	+3.9%	---
TAKE-OFF ANGLE		Mean	SD	Mean	SD
GRAB	Pre	-5.2	8.5	-8.1	6.1
	Post	-5.1	7.6	-7.6	6.2
	Change	+2.0%	---	+6.6%	---
TRACK	Pre	-10.8	7.3	-13.3	7.4
	Post	-10.2	7.6	-10.1	5.6
	Change	+5.9%	---	**+31.7%***	---
SWING	Pre	-6.8	7.3	-9.3	7.1
	Post	-6.2	6.9	-7.6	6.9
	Change	+9.7%	---	+22.3%	---
ENTRY ANGLE		Mean	SD	Mean	SD
GRAB	Pre	41.0	6.9	38.0	7.9
	Post	39.8	7.5	39.3	6.0
	Change	-3.0%	---	+3.3%	---
TRACK	Pre	40.7	6.6	38.3	8.0
	Post	40.7	8.1	39.8	6.3
	Change	0.0	---	+3.8%	---
SWING	Pre	38.6	6.5	35.9	7.1
	Post	39.1	7.4	37.2	6.9
	Change	+1.3%	---	+3.5%	---

Table 5.8: Dive Start Descriptive Data for Temporal Variables

BLOCK TIME		Mean	SD	Mean	SD
		CONTROL		RESISTANCE	
GRAB	Pre	0.93	0.05	0.93	0.07
	Post	0.96	0.10	0.95	0.05
	Change	+3.1%	---	+2.1%	---
TRACK	Pre	0.96	0.07	0.97	0.08
	Post	0.95	0.08	0.93	0.08
	Change	-1.1%	---	-4.3%	---
SWING	Pre	1.13	0.10	1.15	0.07
	Post	1.10	0.08	1.11	0.09
	Change	-2.7%	---	-3.6%	---
FLIGHT TIME		Mean	SD	Mean	SD
GRAB	Pre	0.25	0.09	0.24	0.06
	Post	0.27	0.08	0.27	0.08
	Change	+7.4%	---	+11.1%	---
TRACK	Pre	0.27	0.08	0.25	0.07
	Post	0.29	0.07	0.28	0.07
	Change	+6.9%	---	+10.7%	---
SWING	Pre	0.27	0.07	0.25	0.06
	Post	0.29	0.08	0.29	0.07
	Change	+6.9%	---	+13.8%	---
TOTAL TIME		Mean	SD	Mean	SD
GRAB	Pre	1.19	0.09	1.17	0.08
	Post	1.23	0.13	1.22	0.07
	Change	+3.3%	---	+4.1%	---
TRACK	Pre	1.23	0.11	1.22	0.08
	Post	1.23	0.08	1.21	0.11
	Change	0.00	---	-0.8%	---
SWING	Pre	1.40	0.10	1.41	0.07
	Post	1.39	0.09	1.40	0.11
	Change	-0.7%	---	-0.7%	---

Table 5.9: Dive start descriptive data for kinetic variables

HORIZONTAL IMPULSE		Mean	SD	Mean	SD
		CONTROL		RESISTANCE	
GRAB	Pre	176.7	14.0	184.5	17.0
	Post	163.8	10.1	175.9	16.0
	Change	-7.9%	---	-4.9%	---
TRACK	Pre	202.0	26.7	197.6	35.2
	Post	198.2	33.6	221.4	39.0
	Change	-1.9%	---	**+10.3%***	---
SWING	Pre	187.6	15.9	205.6	22.8
	Post	180.9	13.8	196.4	21.6
	Change	-3.7%	---	-4.7%	---
VERTICAL IMPULSE		Mean	SD	Mean	SD
GRAB	Pre	59.2	31.3	58.5	36.0
	Post	62.4	32.4	66.1	23.8
	Change	+5.1%	---	+11.5%	---
TRACK	Pre	74.7	22.4	83.4	37.6
	Post	69.3	36.1	92.0	36.5
	Change	-7.8%	---	+9.3%	---
SWING	Pre	100.3	17.1	105.7	25.0
	Post	110.5	26.8	127.5	35.6
	Change	+9.2%	---	+17.1%	---
HORIZONTAL IMPULSE – FEET		Mean	SD	Mean	SD
GRAB	Pre	168.1	16.2	180.2	20.3
	Post	157.9	11.7	170.0	18.1
	Change	-6.5%	---	-6.0%	---
TRACK	Pre	126.7	22.2	132.1	24.6
	Post	121.3	23.3	126.4	22.7
	Change	-4.5%	---	-4.5%	---
HORIZONTAL IMPULSE – HANDS		Mean	SD	Mean	SD
GRAB	Pre	8.6	7.3	4.3	13.3
	Post	5.9	7.5	6.0	7.3
	Change	-45.8%	---	+28.3%	---
TRACK	Pre	75.3	20.6	65.6	32.7
	Post	77.0	19.9	94.0	41.2
	Change	+2.2%	---	**+30.2%***	---
VERTICAL IMPULSE - HANDS		Mean	SD	Mean	SD
GRAB	Pre	166.1	72.8	146.0	68.3
	Post	169.9	77.8	178.2	65.9
	Change	+2.2%	---	+18.1%	---
TRACK	Pre	195.4	62.0	187.8	86.9
	Post	222.5	90.1	240.8	75.1
	Change	+12.2%	---	+22.0%	---

Table 5.8 shows that no significant group by time differences existed within the techniques for any temporal variable ($p > 0.05$). A general trend existed in all three starts whereby both groups increased in flight time. Whilst not significant, the R group improved more than the C group in the time of flight for all three starts.

Table 5.9 shows a significant group by time effect within the track start for HI ($p < 0.05$). The increase in total HI was mainly due to the significant group by time improvement of the hand impulse ($p < 0.01$). The swing and grab starts decreased in HI for both groups. Whilst not significant, the R group increased more than the C group in VI for all three starts.

CHAPTER SIX

DISCUSSION

PART 1: A pre-intervention comparison of the three diving techniques.

Flight distance

It was hypothesised that the FD of the track and swing starts would be significantly greater than the grab start, but not significantly different from each other. This was expected based on prior findings of the swing start's superiority over the grab start in flight distance (Gibson & Holt, 1976; Lewis, 1980), mainly due to the ability to build up extra momentum with the full arm swing. The track start was also expected to travel further in the air due to the added contribution of the shoulders and rear positioning of the CG adding to the total horizontal momentum. A Tukey HSD post-hoc test revealed that the FD of the track start was significantly greater than in the grab start ($p < 0.05$). There were no significant differences between the track and swing, nor the grab and swing starts ($p > 0.05$). Therefore, the hypothesis was rejected.

The track start travelled a mean of 0.18m further in the air than the grab start and 0.11m further than the swing start. Whilst the latter was not significant, 0.11m could be quite important in a close race, especially when considering the extra time that would be required to make up this distance in the water when compared to travelling through air as a medium. At a hypothetical swimming speed of 2.0 m/s, it would take 0.06 s to make up 0.11m, which could mean the difference between placing or not placing in a competitive race. A similar reasoning could be used for the 0.07m superiority of the swing start over the grab start. However, a greater FD might not be advantageous if the water entry velocity is less or the time to water entry is longer. This will be discussed in later sections.

The flight distance of the body depends primarily on the speed of take-off, angle of take-off and the height of take-off. According to the formula for the range of a projectile, differences in velocity will have the greatest effect upon the range of the body due to the 'squaring' of the velocity component (Hay, 1993):

$$R = \frac{v^2 \sin\theta \cos\theta + v \cos\theta \sqrt{(v \sin\theta)^2 + 2gh}}{G}$$

In the current study, there were very little differences between the techniques in the height of CG at take-off and water entry. Within most participants, only 0.01-0.02m varied between techniques, which would have negligible effect on the flight distance. Therefore, height of CG at take-off and entry were not used as variables in a statistical comparison of the dive techniques. The take-off velocity is the most important factor in determining flight distance and will therefore be discussed in detail.

Take-off velocity

It was hypothesised that the track and swing starts would leave the blocks at significantly higher velocities than the grab start, but not significantly different from each other. This hypothesis was formulated as it was expected that more horizontal impulse would be produced during the track and swing starts than in the grab start, mainly due to a greater arm contribution to force production. The track start was significantly faster than both the grab and swing starts ($p < 0.01$). Of the 23 participants, 21 found that the track start generated the highest take-off velocity. However, there was no significant difference in V between the grab and swing start ($p > 0.05$), thus rejecting the hypothesis.

The latter finding was in agreement with several studies (Ayalon et al., 1975; Bloom et al., 1978; Bowers & Cavanagh, 1975; Shierman, 1979). Similar to the current study, Ayalon et al. (1975) and Bloom et al. (1978) used inexperienced swimmers who were trained in the swing and grab starts. Therefore, the swing start may not have been performed at the same quality of the other starts due to its more complex coordination requirement. However, Bowers and Cavanagh (1975) and Shierman (1979) had similar findings using swimmers experienced in both starts. The increased pre-tension of the legs during a grab start may, in part, compensate for the extra momentum that can be built up by using an arm swing technique. This would suggest that any advantage gained using the grab start is due to a shorter time spent on the blocks and not from any events arising after take-off (Bowers & Cavanagh, 1975).

No research to date has investigated the effectiveness of the track start with the body mass positioned over the rear leg. It was suggested that this may have possible biomechanical advantages over the grab or front-weighted track starts in terms of force production, but may take longer to leave the blocks. No studies have found the front-weighted track start to generate a higher velocity than the grab start (Counsilman et al., 1988; Shin & Groppel, 1986; Stone, 1988; Welcher & George, 1998). However, the current study showed that the rear-weighted track start left the blocks with a mean velocity of 0.30 m/s and 0.27 m/s faster than the grab and swing starts, respectively (see Table 5.1). Guimaraes and Hay (1985) stated that a good swimming start requires a fast entry into the water, followed by a streamlined position in order to reduce drag and minimise the loss of horizontal velocity. As the angles of entry were not significantly different between techniques ($p > 0.05$), then the track start technique should begin the gliding phase at a faster speed than the other two techniques, assuming that air resistance is negligible.

An effective dive also requires a minimal time to be spent on the block, requiring a trade-off between the time spent on the block and the amount of force produced. A short block time can give the swimmer a psychological advantage of being in front at the start and diving into smooth water (Juergens, 1994). However, shorter block times would disadvantage the swimmer if the amount of force and resultant speed of entry produced on the block was sacrificed for time. As a mean block time of only 0.03 s separated the grab and track starts, it could suggest that the track start is a more effective starting method as its take-off velocity, and hence flight distance, is considerably greater.

The grab start was developed with this trade-off concept in mind and was generally shown to be more effective than the swing start (Bowers & Cavanagh, 1975; Bloom et al., 1978; Lewis, 1980). The forward track start was also developed as it was considered that the more forward CG and lower body position would decrease the block time without sacrificing the take-off speed. However, several studies found that the flight distance and horizontal speed were adversely affected (Allen et al., 1999; Ayalon et al., 1975; Zatsiorsky et al., 1979). This could best be explained in that there is little weighting of the rear leg and a small resultant contribution to horizontal force production. Therefore, shifting the body weight backwards (rear-weighted track start) positions the mass over the rear leg and could increase the loading of the leg extensor muscles. This is particularly so for the rear leg and the backward arm pull may also increase the amount of force production. However, this rear-weighted body position required a greater horizontal displacement of the CG on the block, which could contribute to an increase in the amount of time spent on the block. However, as the arms were not used primarily to pull the body down towards the water, less time was needed to displace the CG in the vertical direction.

Entry angle and take-off angle

The EA was calculated by taking the angle made by the line between the wrist and hip joint markers and the horizontal. This was deemed to be more informative than using the angle of the CG's path to the horizontal at the point of finger entry into the water, which gives little indication of the body position prior to entry and, therefore, streamlining. The entry and take-off angles were used to indicate whether there were any changes in body position due to different techniques performed on the block.

A null hypothesis was used, stating that neither the EA or TA would be significantly different for any of the starts. Results showed that there were no significant differences between the body positions of the techniques at the point of entry, hence supporting the null hypothesis for entry angle. The mean entry angles in this study were very similar to those of Pearson et al. (1998) who recorded 42.6^0 for the grab start; and, Kirner et al. (1989) who found 40.3^0 and 39.9^0 for the grab and forward-weighted track starts, respectively. This could suggest that there is little difference in body position within subjects during flight and water entry due to technique.

However, a significant difference existed between starts in their take-off angles, thus rejecting the null hypothesis. As the feet left the block, the CG was moving at a significantly lower angle in the track start than the grab start (see Table 5.1). One possible explanation for the lower angle of the track start could be due to the instrumentation, whereby the bottom edge of the hand-bar was mounted 5cm below the front edge of the block. This may have an effect of pulling the body down more than if the block was grasped at the same level as the feet. It was not known if the TA's were close to optimum for each starting technique. Whilst significant, a mean difference of 5.4^0 would have minimal effect on the flight distance, according to the range formula in Hay (1993). However, the results for the grab and swing starts were in line with the findings of Hobbie (1980) and Wilson and Marino (1983). The studies of Allen et al.

(1999), Jeurgens (1994) and Stone (1988) showed that the TA of the front-weighted track start tended to be less than the grab start, although not significant ($p > 0.05$).

In the current study, the grab and swing starts were characterised by an initial vertical drop of the CG, followed by a gradual downward path towards the water (see Figure 6.1). In contrast, the rear-weighted track start had considerably less vertical displacement of the CG throughout the block phase than either the swing or grab starts. Using the track technique it may be more advantageous, in terms of take-off angle, to begin with a lower hip position (at about shoulder height) as this may help to project the body upwards and prevent the arms pulling the body towards the water. However, this would result in a smaller angle of the rear leg, potentially a mechanically weaker position for maximal force production.

Block time

It was hypothesised that BT for the grab and track starts would not be significantly different from each other, but both techniques would be significantly faster off the blocks than the swing technique. This was based on the findings of previous studies and biomechanical knowledge of the grab and swing starts (Bowers & Cavanagh, 1975; Roffer & Nelson, 1972). When compared to the grab start, it was thought that the extra arm-pull required in the track start would help to account for the greater horizontal distance the CG would travel by increasing the body's acceleration. No significant difference in BT was found between the grab and track start, with just 0.03 s separating them. However, the swing start was found to be significantly slower ($p < 0.001$) than either the grab or track technique. Hence, the hypothesis was supported by these results.

The mean difference of 0.21 s between the grab and swing technique was greater than in the reviewed literature. The Bowers and Cavanagh (1975) study of six females of similar age to those in this current study, but who were experienced in both starts, found the grab starters left the blocks 0.17 s faster than the swing starters ($p < 0.001$). Bloom et al. (1978) attributed the grab start shorter take-off times over the swing start to a lower and more forward CG. Therefore, less time was required to push/pull the body towards the water. More time is also required in order to complete the full circular arm swing.

Whilst studies comparing the grab and swing techniques generally agreed that the grab start was significantly quicker off the blocks than the swing start, the mean differences were smaller than in the current study (Bloom et al., 1978, 0.09 s; Gibson & Holt, 1976, 0.10 s; Lewis, 1980, 0.06 s). This may be due to different samples studied. Lewis (1980) used inexperienced males and Gibson and Holt (1976) used a mixed sample, experienced in both starts. In the current study, the swing start might have been performed at a lower skill level than either the grab or track start, reflected mainly by the large differences in block time. However, it was noted from the video and force traces that it took considerably longer for participants to begin the forward arm swing than to move in the grab and track starts. Disregarding BT, the swing start was nevertheless, marginally superior to the grab start in its flight distance and velocity. As the swing start requires more coordination of body segments and timing than the other techniques, it is possible that inexperienced swimmers require more learning time on this technique.

Wilson and Marino (1983) used a mixed gender sample and found the movement time of the grab start to be 0.16 s faster than the swing start. The difference in overall block time may have been even greater had the reaction time been included in the analysis. Two previous studies (Bowers & Cavanagh, 1975; Bloom et al., 1978) found the reaction time of the grab start to be 0.02 s faster than the swing start, but this was not significant. However, reaction time measures may not be accurate as they were defined as the time from the start signal until the first movement was made, using video as a means of measurement. Reaction time could not be accurately measured from the force-time curves in the current study. However, when viewing the video and force graphs of the current study, it was observed that participants generally took longer to produce the first movement during the swing start than either the grab or track starts. In the force traces of the swing start (Figure 5.3), there was a slight increase in vertical and horizontal force prior to the arm swing as the participants reacted to the starting stimulus, probably due to extra pre-tensing of the muscles in preparation for the dive. Time on the block could have been shorter in the swing start had the muscles been pre-tensed and in a more active state. This could in part help to explain the relatively long BT of the swing start when compared to the grab and track starts, whereby the legs were already pre-tensed and more active prior to the start. Increased pre-tension of the muscles could reduce the reaction time of the swimmer following a starting signal (Pearson et al., 1998).

Previous studies have shown the track start, with the body mass positioned over the front leg, to be faster off the blocks than the grab start (Ayalon et al., 1975, Shin & Groppel, 1986, Stone, 1988). However, no studies have investigated the track start with the mass positioned over the rear leg. Originally, it was considered that this rear weighting was a disadvantage due to the extra distance and resultant time the body's CM would need to move to reach full extension at take-off. However, observed fluctuations in the vertical displacement of the CM on the block for the track start were less than the other techniques (see Figure 6.1), which may help to offset the extra time required to move the CM horizontally further. It was also perceived that the arms contributed considerably more force from starting in this position, and, therefore, could increase the forward momentum of the body.

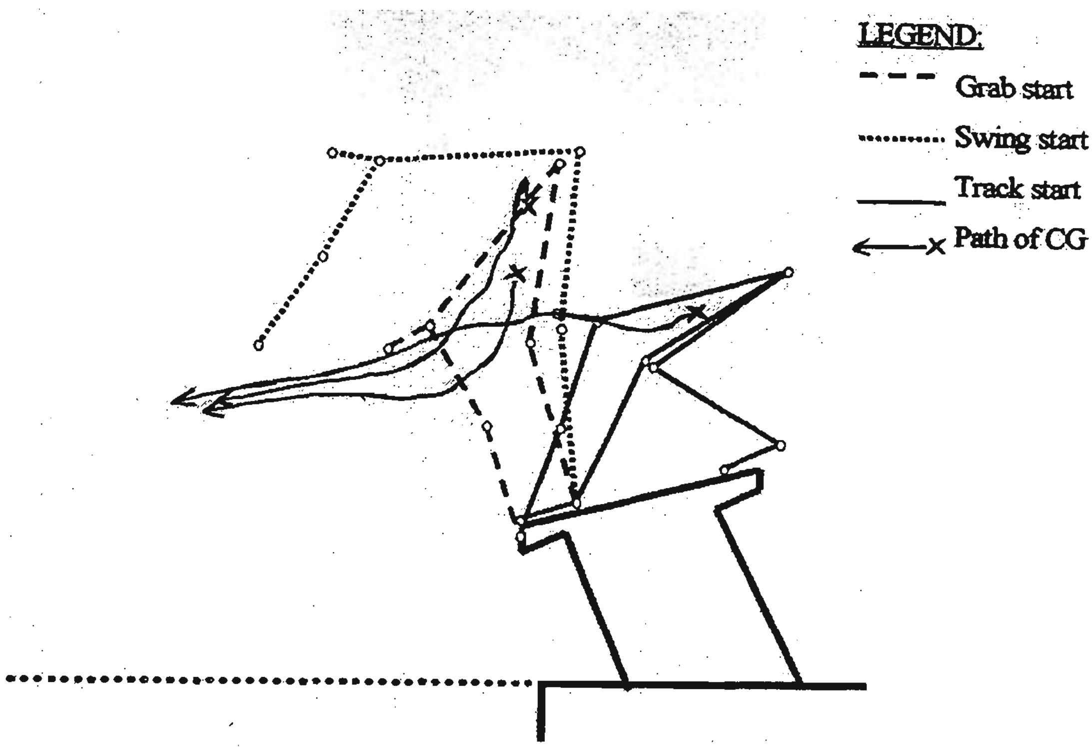


Figure 6.1: Segmental models of the starting positions for each starting technique

Flight and total time

It was hypothesised that the track and swing starts would have a significantly longer FT than the grab start, but not with each other. This was based on similar reasoning to the velocity and flight distance hypotheses – that the techniques of these two starts would allow greater momentum to be built up on the block due to their increased arm contributions. No significant differences existed between any of the start techniques for FT (see Table 5.3), therefore supporting a null hypothesis. Only 0.01 s separated the three starts in flight time. Therefore, any differences in the TT to finger entry were due to the differences in block time. No significant difference in TT existed between the grab and track start ($p < 0.001$) with only 0.04 s separating the two starts. The swing start was significantly slower to the moment of finger entry into the water than either the grab or track starts ($p > 0.05$). This supported the hypothesis relating to BT and total time.

Kinetic variables

Several kinetic variables were measured by the force plate (forces applied through the feet) and load cells (forces applied through the hands), including peak force and impulse in the horizontal and vertical planes of movement. The track start produced significantly greater HI than either the grab or swing start ($p < 0.05$), which were not significantly different from each other. These results were supported by the findings of Shierman (1979) and Juergens (1994). The hypothesis was rejected, as it was expected that both the track and swing starts would produce significantly greater amounts of HI than the grab start. The hypothesis for HI was developed using the same reasoning as the velocity and flight distance hypotheses, as HI is a major determinant of take-off velocity (Breed, 1998; Hay & Guimaraes, 1983; Jeurgens, 1994; Miller et al., 1984).

The track start had a mean HI of 18.9 Ns greater than the grab start, which would in part help to account for its superiority in V and flight distance. However, the HI of the track and swing start was similar, partly attributable to the considerably longer time spent on the block in the swing start (F x t), which might suggest a more inefficient performance of the swing technique. This was supported by the swing start having a slower take-off velocity than the track start (Table 5.1). Therefore, the 'trade-off' between force and time might not have been close to maximal in the swing start. However, the swing techniques used by participants enabled them to generate a slightly greater velocity and flight distance than in the grab start, although not significant ($p > 0.05$).

When the total horizontal impulse was separated into feet and hand contributions, the grab and track starts showed two quite different starting mechanisms. The main purpose of the arms in the grab start was to act as a 'brace' in which the legs could push against, with a very small amount of horizontal push as the body began to fall forward towards the water. Almost all of the horizontal drive came from the legs during the grab start, which was in support of previous literature (Cavanagh et al., 1975; Guimaraes & Hay, 1985). In contrast, about 35% of the total horizontal impulse came from the arms in the track start (see Table 5.2). Due to the backward body position of the track start, the legs were primarily pushing against the direction of intended travel and therefore creating a negative horizontal impulse, hence considerably lower HI of the feet than in the other techniques. Initially then, the role of the arms was to pull back against the block in order to overcome the body's inertia and accelerate the CG forward. The role of the arms then decreased as the legs began to push back against the block (see Figure 5.2).

The swing start produced significantly greater VI than both the grab and track starts, whilst the track and grab start almost reached significance at a 95% level of confidence (see Table 5.4). This finding rejected the research hypothesis, in which the track and swing starts were expected to have significantly greater VI than the grab start, but not with each other.

Unexpectedly, the arms contributed more vertical impulse during the track start than in the grab start (see Table 5.2), as participants were instructed to pull back against the bar as forcefully as possible, not upwards to pull the body down towards the water. As mentioned earlier, this finding might have been in part due to the hand-bar being mounted 0.05m below the feet and, therefore, the arms could have contributed more to pulling the body downwards rather than forwards. The extra horizontal and vertical impulse provided by the arms (see Figure 6.2) might help to explain the superiority of the track start over the grab and swing starts in take-off velocity and flight distance. Note that the VI of the feet was adjusted for effect of body mass.

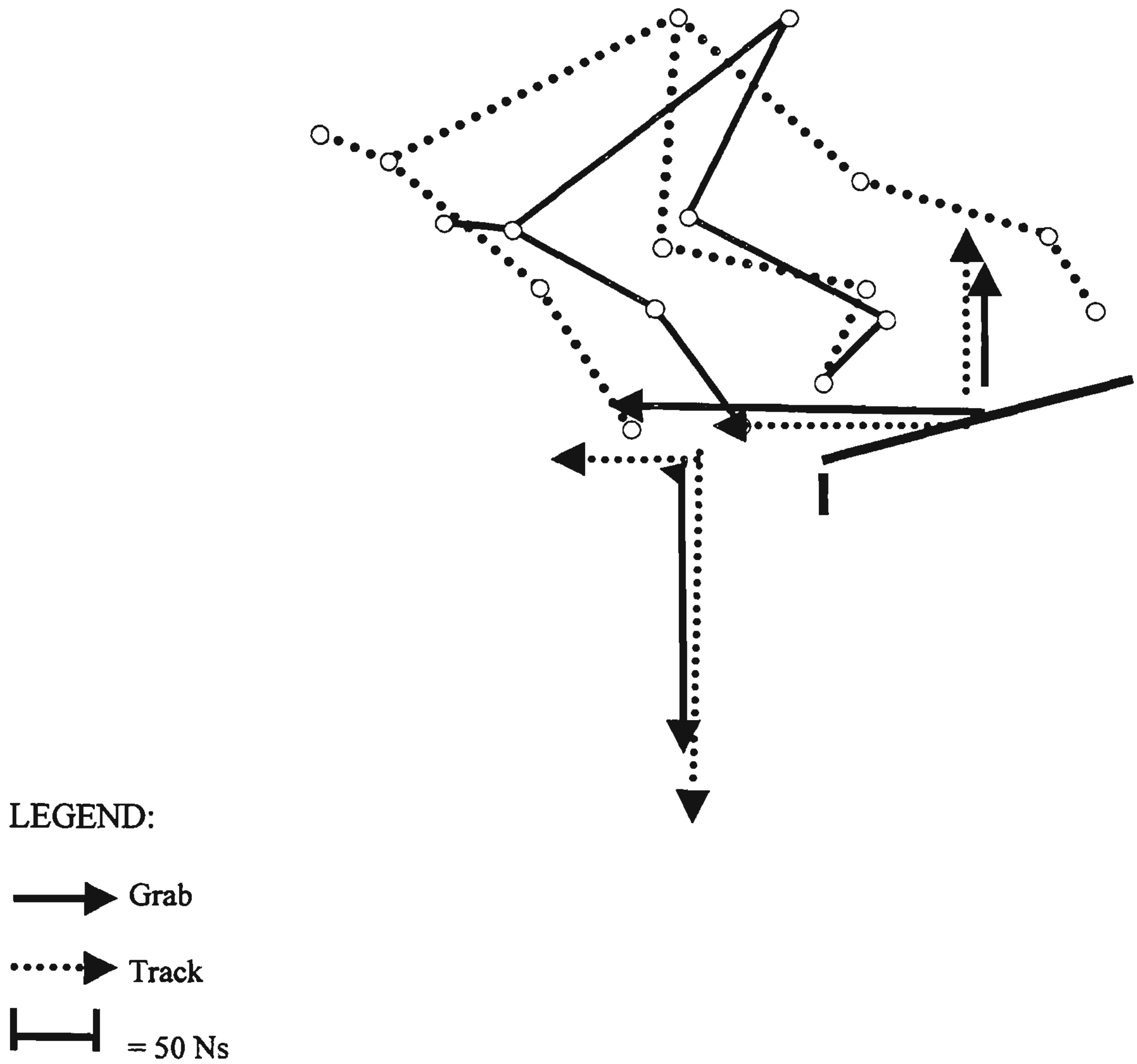


Figure 6.2: Schematic horizontal and vertical force components

Conclusion to part one of study

The findings of the current study support the possible superiority of the track technique over the grab and swing starts. Whilst the track starters entered the water an average of 0.04 s slower than the grab starters, they travelled 0.18m further in the air and entered at a significantly higher velocity. Therefore, assuming similar body positions at entry and underwater, the rear-weighted track technique should be more effective. When comparing the track to the swing start, the track starters travelled 0.11m further in flight ($p > 0.05$) and entered at a significantly higher velocity. Even when ignoring the significant time difference to entry (as it is not a factor in a relay changeover), the track technique was potentially more effective than the swing start in this study.

Once a swimmer has established their most appropriate technique, they might be able to improve their take-off velocity and flight distance further by developing greater leg power and jumping ability. Previous researchers have suggested a positive relationship between jumping ability and starting performance (Adams, 1986; Breed, 1998; Miyashita et al., 1992; Zatsiorsky et al., 1979). However, no research to date has investigated the effect of a resistance-training program on diving performance.

<u>PART TWO:</u> The effect of resistance training on swimming starts

<u>Relationship between dry-land tests and dive performance</u>

Using the pre-test data, the dry-land tests were correlated with FD (which was used as a key measure of dive performance). The VJ was correlated most highly of all tests to FD in all three starts ($p < 0.001$). This finding was expected, as the VJ uses similar muscle groups to the swimming start. In addition, the muscle groups are recruited mainly simultaneously, rather than sequentially, during the VJ (Hudson, 1986; Lees & Barton, 1996). Robertson and Stewart (1998) confirmed a similar contribution of joint moments and coordination patterns for the grab start in swimming. However, the swim start would have higher skill associated with it, as an optimal angle of take-off must be found along with a forward rotation of the body.

The highest correlation between the VJ and FD of the swing start (see Figure 5.7) might be attributable to the similar movement patterns involved between the two actions. A similar reasoning could be used for the overall higher correlation of the VJ and FD than the CMJ and FD for all three starts, in that the extra muscle coordination and skill involving the use of the arms most closely resembles the movement patterns of the starts. Both the VJ and swim starts involve complex actions involving the ankle, knee, hip, elbow and shoulder joints.

The squat tests of power (SQ40) and strength (SQ25) were not significantly correlated with FD in any start technique ($p > 0.05$). This might be attributable to the higher level of skill associated with diving. Therefore, skill and coordination might be more important factors in determining dive performance than strength and power in the current study. The significant correlation of the OT and OTB tests with the FD might support this, in that they involved higher levels of skill, such as release angle and greater muscle coordination, than the squat tests. The correlation matrix can be found in Appendix O.

Dry-land tests

The significant group by time MANOVA result ($p < 0.0001$) supported the first hypothesis, which stated that the resistance training would improve performance in the dry-land tests. The follow up univariate test indicated that three of the six tests, the VJ, CMJ and SQ40, improved in performance due to training (see Table 5.6). The SQ40 test was included as a direct measure of lower body power output and a less-skilled measure of leg extensor power than the CMJ, which involves greater coordination and timing of body segments (leg and back extensors). As performance in SQ40 and the jumping tests increased, the 9-week training program was successful in achieving its primary aims of improving muscular power and jumping ability.

The 5.3cm (12.3%) increase in VJ height of the training group was similar to the significant findings in the studies of Bauer et al. (1990), Blattner and Noble (1979), Holcomb et al. (1996), Lyttle et al. (1988) and, Poole and Maneval (1987). The training periods of all these studies were between eight and ten weeks. In the study of Poole and Maneval (1987), VJ performance was measured throughout training and showed that a training plateau was not reached by the tenth week. This might suggest that greater gains could be made in these studies with longer training periods. The training period of the current study was limited to nine weeks with a two-week maintenance program during semester holidays. However, most of the research in this area of study has used male sample groups, making it difficult to make direct comparisons with the current study.

There was a significant time effect ($p < 0.0001$) for all tests (MANOVA). The C group improved marginally in all tests, which might suggest that participants had retained the skills for the tests from the pre-test session. The SQ25 test of squat strength improved over time ($p < 0.01$), but not for time by group, even though the R group increased maximum strength by 12kg compared to the C group's 3.5kg. Part of this improvement in strength could be due to an increase in body mass by both groups of approximately 1kg. However, the training program was periodised so that only the first three weeks emphasised strength, with the main emphases during weeks 4-9 being on developing muscular power and jumping ability. Whilst some strength exercises were included in the latter parts of the program, they were only intended for maintenance purposes (Kraemer & Newton, 1994). It would not be desirable to have large increases in muscle mass due to strength training in swimming, as this could reduce the swimmer's buoyancy (Adams, 1986; Lyttle & Ostrowski, 1994). Participant pre-test squat strength (SQ25) in the current study was about 20kg more than in the study of Ashley and Weiss (1994), who used 50 females of similar age to those in the current study. Using this as a direct comparison, participants in the current study had a good initial base-strength level prior to training. Therefore, the early general strength training was mainly to condition the neuromuscular system to help reduce injuries and muscle soreness associated with high intensity jumping and power exercises.

The OT and OTB tests were not improved by training. These tests were considered to measure shoulder power and back extensor/shoulder power, respectively. Less emphasis was placed on isolated shoulder strength and power exercises than jumping ability in the training program. However, similar small improvements were found in both the C and R groups, which might suggest that the participants had not fully learned the skill and coordination of the techniques. As these tests involved a high amount of skill and had an unusual movement pattern for the participants, they might not have been sensitive to training improvements of the upper body. One further skill variable of the throwing tests that the other tests did not have, was finding the optimal angle of release. The VJ and CMJ tests were quite specific to many movement patterns involved in the training exercises (i.e., jump squats, weighted jumps), where as the throwing tests were not.

Dive start variables

Kinematic measures

Results showed that no significant differences ($p > 0.05$) existed for group, time or group by time effects for either FD or V (see Appendix M), thus rejecting hypothesis two. The limitation of small participant numbers in each group (C=11 and R=12) might have decreased the possibility of reaching significance. Therefore, non-significant trends will also be discussed as a follow up to significant results.

As discussed in part one, FD is a very important performance variable in dive starting, particularly as the body can travel considerably faster through the air than in water (Miller et al., 1984; Robertson & Stewart, 1998). Resistance training did not significantly improve the FD of any starting technique ($p > 0.05$). This finding was unexpected, as VJ ability improved considerably whilst it correlated highly with FD in all three techniques. This would suggest that improvements in jumping ability were not directly transferred to the skill of diving. Even though similarities exist in the timing and muscle segmental contributions of the VJ and grab start (Robertson & Stewart, 1998; Shierman, 1979), improvements in jumping ability might not be observed in dive performance due to the extra skill involved in starting. For example, dive starting requires changes in body position during flight and finding an optimal take-off angle.

When comparing the three techniques in FD, some non-significant trends were observed. No change in FD occurred in the grab start for the R group (see Table 5.7). However, the mean FD of the track and swing starts changed by 0.09m and 0.06m, respectively, when comparing the C and R groups. This might suggest that some jumping skill improvement has transferred to the track and swing start, but not the grab start. Whilst not significant ($p > 0.05$), such improvements gained in flight could equate to approximately 0.03-0.04 s time advantage in the water. This difference could be vital in determining places of a 50m sprint race.

Take-off velocity is the main determinant of FD (Hay, 1993), thus similar trends would be expected for both variables. The univariate analysis found that V of the track start increased significantly ($p < 0.05$) due to training. Whilst the R group improved by only 0.06 m/s, the C group decreased by 0.13 m/s and, therefore, the significant effect might in part be due to the C group performing the track start at a lower level of skill during post-testing. Whilst not significant, the swing start improved by 0.14 m/s when comparing the two groups, which might in part account for the improvement in flight distance. Little change in V was found for the grab start. A possible explanation for this finding could be the relatively small contribution to force production and power from the arms during the grab start when compared to the track and swing starts. Vertical jump studies have found that the arms contribute about 15% of the body's total power in jumping (Davies & Jones, 1993; Shetty & Etnyre, 1989).

As vertical velocity of the CG at take-off determines the height of a VJ (Oddson, 1989), it is logical that an improvement in VJ performance could lead to increased V in a dive start. However, much smaller increases due to training were made in V when compared to jump height. This might suggest that the improved skill of jumping was not transferred directly to the start, particularly the grab technique, which showed no improvements in FD or velocity.

No significant or non-significant trends were observed for the entry angle of any start due to training, suggesting that the body position prior to entry was unaffected by improvements in jumping ability. However, hypothesis two was rejected, as a significant multivariate time by group effect ($p < 0.05$) was found for the take-off angle (TA). Whilst a similar trend was found for all starts, in that the R group increased in TA more than the C group, only the track start increased significantly ($p < 0.01$), suggesting that improving jumping ability increased the take-off angle. This would also help to account for the increase in FD and V, as the TA of the track start was very low when compared to the other techniques and other literature (Breed, 1998; Hobbie, 1980; Pearson et al., 1998; Stone, 1988).

The higher TA could be due to an increase in vertical velocity during the start, also responsible for improved VJ performance. An increase in vertical velocity, and hence TA, might indicate a need for practising the dives to retrain the changed neuromuscular properties due to the resistance training. Bobbert and Van Soest (1994) used a model to simulate vertical jump squats. When the input stimulation was increased (representing higher strength levels) and timing remained the same, jump height decreased. Thus, an increase in power output might result in a decrease in jump height unless jumping is practised so that skill and control mechanisms are re-optimised. This is a likely explanation for the very small improvements in diving performance when compared to the increases in VJ height. Therefore, it is quite possible that larger improvements would have been observed in dive performance had they been practised throughout the resistance-training period in order to adapt the timing of the muscles.

Temporal measures

Hypothesis three was accepted in that no temporal variable significantly changed due to training ($p > 0.05$). Non-significant trends were observed for block time (BT) and flight time (FT). For the grab start, both groups spent marginally longer on the blocks (see Table 5.8) in the post-testing. However, the R group decreased their BT slightly more than the C group for the track and swing starts. This could suggest that these starts were being performed at a higher level of skill following the resistance-training period - particularly for the swing start, which was leaving the blocks comparatively slower than in other studies (Bowers & Cavanagh, 1975; Gibson & Holt, 1976). When both groups were analysed collectively, the track start left the block 0.01 s faster than the grab start, compared with the grab start's 0.03 s superiority in the pre-test.

All three starts had an increase in flight time (FT), particularly the R group ($p > 0.05$). This helps to explain the slightly further FD achieved in the track and swing starts. A longer FT might also suggest that the starts were being performed at a slightly higher level of skill than in pre-testing. The small improvement in the C group's performance could suggest the diving skills were well retained. However, as only 0.02-0.03 s differences were observed between or within groups for FT, no decisive conclusions can be formulated.

Kinetic measures

The total horizontal impulse (HI) of the track start increased significantly due to resistance training ($p < 0.05$). However, both groups within the grab and swing starts had similar decreases in HI (see Table 5.9), suggesting that improvements due to training were only transferred to the track start in the horizontal direction of force production. The HI was broken down into feet and hand impulse (HIF and HIH) for the grab and track starts and analysed separately. No improvements in HIF were found for either start. However, the HIH of the track start increased by about 30% ($p < 0.01$) due to training, which would explain the significant improvements in HI and take-off velocity. This further supports the theory that the arms have a large role in providing horizontal momentum of the body during the rear-weighted track start. Therefore, it would have been expected that significant improvements would have been made in the dry-land overhead throw tests, but they might not have been specific enough to the dive. Even though the HIH increased for the grab start, the role of the arms in producing horizontal drive was negligible (approximately 6N).

Whilst not significant, it was observed that training might have improved the vertical impulse (VI) in all three starts (see Table 5.9). This finding would help to account for the increased take-off angles of the starts – particularly the track technique. When the hands were analysed separately (VIH), an improvement in VIH was noticed in the track and grab starts due to training. This might further support the concept that the role of the arms in the vertical direction is to pre-tense and increase the loading of the leg extensors (Cavanagh et al., 1975; Hay & Guimaraes, 1983; Juergens, 1994).

Conclusion to part two of study

The findings were unexpected, as it was considered that the swing start had the most specific muscle movement patterns to vertical jumping. Due to the plyometric and explosive training, the participants' ability to utilise the elastic and neural benefits of the SSC would have been enhanced (Wilson et al., 1996). One possible reason for the lack of skill transfer could be due to the slower speed of muscular contraction, particularly during the eccentric phase (Harman et al., 1990). This slower contraction speed is needed to allow for forward rotation of the body to move into its line of push. The track start might have had better improvements in performance due to training than either the grab or swing start as it appears to use a slightly different mechanism for starting. The body is pulled directly forwards with little 'dipping', therefore less emphasis is placed on the SSC, rather than on pre-tensing of the leg-extensors.

The performance of the track start might have been enhanced due to an improvement in jumping ability. It appears that improved jumping ability might have an effect on the vertical components of all three techniques, suggesting that there was not a direct transfer of skill to the grab and swing starts, as no significant improvements were found for horizontal force components or flight distance. This finding would further support the need to adapt the control mechanisms to the diving techniques through practice (Bobbert & Van Soest, 1994).

CHAPTER SEVEN

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

A swimmer's take-off speed might be improved by altering starting technique or by increasing power and jumping ability. The current study aimed to establish whether the grab, swing or rear-weighted track start was more effective by measuring several temporal, kinematic and kinetic performance variables. The study's second aim was to establish the effect of a resistance-training program, aimed at improving jumping ability, on the diving performance of the three dive techniques.

Twenty-three non-competitive swimmers participated in the study (mean age 19.9 ± 2.4 yrs). Participants practised each start equally 30 minutes a week for an eight-week period. Testing involved two maximal trials of each technique in random order. Feet and hand forces were measured using a Kistler force plate and load cells, respectively. Kinematic and temporal variables were measured using video. Analyses of variance and post-hoc tests were performed for nine dependent variables. The track start was significantly superior to the grab start in flight distance, take-off velocity and horizontal impulse, and significantly superior to the swing start in block time, total time, take-off velocity and vertical impulse. The grab start was significantly superior to the swing start in block time, total time and vertical impulse. No significant differences were found between any of the starts in flight time or entry angle. The arms provided little horizontal drive in the grab start whereas they contributed just over one-third of the total horizontal impulse in the track start and considerably more vertical impulse than the grab start. The findings suggested a greater effectiveness of the track start over the grab and swing starts.

In the second part of the study, participants were randomly assigned to a control group (N=11) or a resistance-training group (N=12), who trained three times a week for nine weeks. Six dry-land tests were performed for pre- and post-testing – two countermovement jumps (with and without arms), two CES squats (25^0/s and 40^0/s bar speed) and two overhead shot throws (with and without back extension), with the best of three trials being recorded. Post-testing of the three dive techniques was also performed using the same pre-test procedures and instrumentation. Resistance training significantly improved performance in the dry-land tests ($p < 0.0001$). Resistance training had no significant effect on any temporal, kinematic or kinetic variables within the grab or swing starts. Significant training improvements ($p < 0.05$) were found within the track start for take-off velocity, take-off angle and horizontal impulse of the hands. Non-significant trends toward improvement were observed within all starts for vertical force components, suggesting a need for practising the dives to retrain the changed neuromuscular properties. Results implied that the improved skill of vertical jumping was not transferred directly to the start, particularly in the grab technique.

Part one: Conclusions

On the basis of the findings in part one of this study it was concluded that:

1. The flight distance of the track start was significantly greater than the grab start ($p < 0.05$), but no significant differences existed between the track and swing, nor the grab and swing starts.
2. The track start recorded a significantly faster take-off velocity than the grab ($p < 0.01$) and swing ($p < 0.01$) starts. There was no significant difference in take-off velocity between the grab and swing start.

3. No significant differences existed between any of the starts in the body angle at entry ($F = 0.733$, $p = 0.484$).
4. The track start had a significantly lower angle of take-off than the grab start ($p < 0.05$). No significant differences existed between the track and swing nor the grab and swing starts.
5. No significant difference in block time or total time was found between the grab and rear-weighted track start ($p > 0.05$). However, both the grab and track starts were significantly quicker to leave the blocks and enter the water than the swing start ($p < 0.0001$).
6. There were no significant differences in flight time between any of the start techniques ($F = 0.254$, $p = 0.777$).
7. The total horizontal impulse of the track start was significantly greater than the grab start ($p < 0.05$), but no significant differences existed between the track and swing, nor the grab and swing starts.
8. The swing technique produced significantly more vertical impulse than the grab ($p < 0.001$) and track techniques ($p < 0.01$). No significant difference in vertical impulse was found between the grab and track starts.

Part two: Conclusions

On the basis of the findings in part two of the study it was concluded that:

1. Vertical jump, countermovement jump and CES squat power test performance significantly improved due to resistance training ($p < 0.05$).
2. No significant improvements due to training were found for CES squat strength, overhead throw and overhead throw with back extension tests.
3. Take-off velocity and take-off angle significantly increased for the track start due to resistance training ($p < 0.05$).

4. Total horizontal impulse and horizontal impulse of the hands significantly increased for the track start due to resistance training ($p < 0.05$).
5. Resistance training had no significant effect on the grab or swing starts within any dive start variable ($p > 0.05$).

Recommendations

It is recommended that:

1. A comparison of the three start techniques be made with elite or high-performance swimmers
2. Both female and male sample groups are used in comparing the starting techniques
3. A criterion distance including part of the gliding phase is used as a more realistic measure of diving performance
4. The rear-weighted track start is investigated further in terms of joint angles and hip height aimed at providing maximal push and appropriate take-off angle
5. The rear-weighted track start is investigated when grasping the handles at the sides of the block, as this might improve the joint angles, take-off angle and horizontal arm contribution, thus improving the effectiveness of the technique.
6. The rear-weighted track start is investigated as an alternative start during relay changeovers.
7. Practice of the dive techniques is continued throughout resistance training in order to re-optimise the skill and control mechanisms of the neuromuscular system.
8. Testing throughout training should be performed in order to calculate when a training plateau is reached in both the dry-land training and dive start technique training.
9. Work and power around the joint moments be calculated for each start technique to provide information on joint contributions to the overall performance. This would

allow closer comparison to vertical jumping performance and assist with designing a specific training program.

10. The rear-weighted track start should be practised during training in order to compare it with the individual's current preferred technique.
11. Individual swimmers should experiment with using different body positions of the rear-weighted track start eg. foot spacing, hip height, as slight variations might improve the performance.
12. If starting block handles are available, the rear-weighted track start should be practised with and without grasping the handles in order to identify preference and superiority of each method.

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APPENDIX A:

PLAIN LANGUAGE STATEMENT AND PARTICIPANT CONSENT FORM

UNIVERSITY OF BALLARAT
PLAIN LANGUAGE STATEMENT AND INFORMED CONSENT

PROJECT TITLE:	***"The Effect of Resistance Training on the Grab, Swing and Track Starts in swimming"***
INVESTIGATOR:	**Ray Breed**
PLAIN LANGUAGE STATEMENT	• The aim of the study is to establish the effect of a specific resistance training program on performance in the grab, swing and track starts in swimming. <u>Procedures:</u> • ***11th. May - 20th. July:*** You will learn the techniques of the three different starts during class-times. You will also be required to participate in one 15 minute coached training session per week at a time provided. • ***27th. July - 7th. August:: Pre-testing.*** You will be filmed performing three trials of the three dive techniques. You will also perform two different vertical jumping tests, two squat tests and two overhead seated-shot throw tests. • ***10th. August - 23rd. October:*** During semester time (not including the break), you will be randomly assigned to either a control group or a resistance-training group. The control group will not perform any extra training activities outside of their normal daily routines. The resistance-training group will perform three supervised training sessions per week in the U of B toning point. • ***26th. October – 30th. October: Post-testing.*** You will be tested in the three dives and the land-based tests in the same way as the pre-testing session.

1. I, ... of ....

hereby consent to participate as a subject in the above research study.

2. The research program in which I am being asked to participate has been explained fully to me, verbally and in writing, and any matters on which I have sought information have been answered to my satisfaction.

3. I understand that

   - all information I provide (including questionnaires) will be coded by number and stored separately from any listing that includes my name and address.
   - aggregated results will be used for research purposes and may be reported in scientific and academic journals.
   - I am free to withdraw my consent at any time during the study in which event my participation in the research study will immediately cease and any information obtained from it will not be used.

SIGNATURE: .... DATE: ....

APPENDIX B:

INDIVIDUAL PARTICIPANT PRE AND POST DRY-LAND TEST DATA

KEY TO TABLE:

SYMBOL	MEASURE
NO	Participant ID number
MASS	Body mass (pre-test)
PMASS	Body mass (post-test)
HGT	Height (pre)
PHGT	Height (post)
VJ	Vertical jump, with arms (pre)
PVJ	Vertical jump, with arms (post)
CMJ	Vertical jump, no arms (pre)
PCMJ	Vertical jump, no arms (post)
SQ40	CES squat power test (pre)
PSQ40	CES squat power test (post)
SQ25	CES squat strength test (pre)
PSQ25	CES squat strength test (post)
OT	Overhead throw (pre)
POT	Overhead throw (post)
OTB	Overhead throw, with back extension (pre)
POTB	Overhead throw, with back extension (post)

NO	AGE	MASS	PMASS	HGT	VJ	PVJ	CMJ	PCMJ	SQ40	PSQ40	SQ25	PSQ25	OT	POT	OTB	POTB
1	18.75	56	57	171	38	40	28.3	29.6	90.4	116	108.2	131.1	4.92	4.75	7.52	7.86
2	18.75	56	56	157	44	46	28	26.7	114.4	99.2	116.9	126.9	4.32	4.24	6.34	7.45
3	18.5	66	70	170	42	41	27.7	26.2	92.8	105.6	125.9	119.7	5.52	6.1	8.25	8.75
4	19.25	65	65	170.5	48	49	34.1	31.1	132.8	116	111.5	112.5	5.54	5.37	6.64	7.71
5	19.5	63	66	165	38	38	25.2	24.8	112.8	116.3	128.2	125.7	5.51	5.42	10.8	10.38
6	18.75	66	70	167	34	37	20.8	23.4	112.8	110.4	110.8	119.2	4.3	5	7.21	8.17
7	18.75	68	70	175	43	44	27.3	27.3	115.2	108	138.3	121.9	5.06	5.22	7.95	8.2
8	18.75	75	76	170	42	40	24.5	24.2	137.5	133.9	157.4	160.1	4.58	4.39	6.42	6.03
9	21.75	63	63.5	161	43	42	23	25.6	113.6	116.8	154.2	144.3	5.4	5.37	7.28	7.61
10	28	60	61	158	30	31	23.6	25.7	97.2	116.8	132.1	149.4	4.04	4.05	6.74	6.55
11	18.5	58.5	60	163	40	40	31.6	31.8	109.6	109.6	112.8	123.8	5.9	5.9	8.51	8.46
	19.93	63.32	64.95	166.14	40.18	40.73	26.74	26.95	111.74	113.51	126.94	130.42	5.01	5.07	7.61	7.92
1	23	66	70	163	37	42	23.7	27.9	87.2	111.2	102.1	123.6	5.3	5.55	7.84	7.62
2	19	65	65	170.5	45	50	26.9	30.2	100	129.6	94.3	104.9	5.74	6.27	8.99	9.32
3	18.5	62	63	160	42	45	32.4	35.2	134.4	163.2	175.2	174.1	6.81	6.95	10.49	10.3
4	21.5	63.5	63.5	171.5	51	55	34.7	36.7	124.8	166.4	168.1	185.6	6.18	6.66	9.43	10.2
5	19.25	60	60	159.5	34	37	24	26.1	89.6	108.8	101.4	142.3	4.63	4.6	7.51	7.8
6	19.75	62	64	173	41	49	32.1	37.4	110.4	137.6	158.4	155.5	6.1	6.15	8.54	8.7
7	18.75	68	69	158.5	36	38	26.5	30.2	98.4	129.6	129.6	132.7	4.96	5.88	6.68	7.16
8	18.5	66	67	159	28	35	20.9	24.5	100	106.4	125	140.4	4.75	5	8.17	8.45
9	24.25	68	71	162	26	35	19	23.2	103.2	114.8	141.7	142.2	5.12	4.68	6.78	8.16
10	18.25	73	75	167	40	45	27.4	30	134.4	128	132	152.4	5.96	5.44	10	9.12
11	18.5	63	64	160	35	42	28	30.2	140.8	144	152.9	160.3	5.02	5.3	7.42	6.94
12	18.75	67	68	173	38	44	31.5	35.2	137.6	139.6	153.6	164.5	5.54	5.63	8.15	8.33
	19.83	65.29	66.63	164.75	37.75	43.08	27.26	30.57	113.40	131.60	136.19	148.21	5.51	5.68	8.33	8.51

APPENDIX C:

INDIVIDUAL PARTICIPANT RAW DATA FOR DIVE START VARIABLES

<u>KEY TO ABBREVIATIONS:</u>

'G' AFTER ABBREVIATION = GRAB START

'T' AFTER ABBREVIATION = TRACK START

'S' AFTER ABBREVIATION = SWING START

'1' OR '2' AT END = TRIAL NUMBER

<u>EG.</u> BTG2 = BLOCK TIME, GRAB START, TRIAL 2.

BT = BLOCK TIME

FT = FLIGHT TIME

TT = TOTAL TIME

FD = FLIGHT DISTANCE

V = TAKE-OFF VELOCITY

TA = TAKE-OFF ANGLE

EA = ENTRY ANGLE

HI = HORIZONTAL IMPULSE

VI = VERTICAL IMPULSE

HIF = HORIZONTAL IMPULSE, FEET

HIH = HORIZONTAL IMPULSE, HANDS

VIH = VERTICAL IMPULSE, HANDS

HF = HORIZONTAL PEAK FORCE

HFF = HORIZONTAL PEAK FORCE, FEET

HFH = HORIZONTAL PEAK FORCE, HANDS

VF = VERTICAL PEAK FORCE

VFH = VERTICAL PEAK FORCE, HANDS

HT = HAND TIME (TIME OF HAND CONTACT WITH HAND-BAR)

Pre-test Raw Data

NO	GRP	AGE	BTG1	BTG2	BTT1	BTT2	BTS1	BTS2	FTG1	FTG2	FTT1	FTT2	FTS1	FTS2	TTG1	TTG2	TTT1	TTT2	TTS1	TTS2
1	1	18.75	0.84	0.94	0.82	0.82	1.16	1.13	0.10	0.10	0.16	0.14	0.18	0.18	0.94	1.04	0.98	0.96	1.34	1.31
2	1	18.75	0.92	0.88	0.94	0.92	1.10	1.12	0.38	0.34	0.34	0.34	0.36	0.36	1.30	1.22	1.28	1.26	1.46	1.48
3	1	18.50	1.00	0.86	1.10	0.98	1.24	1.26	0.32	0.30	0.28	0.28	0.28	0.28	1.32	1.16	1.38	1.26	1.52	1.54
4	1	19.25	0.96	0.94	0.96	0.95	1.19	1.15	0.36	0.38	0.44	0.40	0.36	0.34	1.32	1.32	1.40	1.35	1.55	1.49
5	1	19.50	0.92	0.94	0.92	0.90	1.06	0.98	0.30	0.32	0.32	0.34	0.32	0.36	1.22	1.26	1.24	1.24	1.38	1.34
6	1	18.75	0.98	0.94	1.01	1.12	1.22	1.16	0.28	0.16	0.24	0.28	0.26	0.28	1.26	1.10	1.25	1.40	1.48	1.44
7	1	18.75	1.00	1.04	1.10	0.98	1.24	1.28	0.14	0.16	0.14	0.20	0.16	0.16	1.14	1.20	1.24	1.18	1.40	1.44
8	1	18.75	1.02	0.88	0.96	0.84	1.10	0.94	0.16	0.18	0.24	0.30	0.18	0.18	1.18	1.06	1.20	1.14	1.28	1.12
9	1	21.75	0.90	0.92	0.86	0.98	1.01	0.90	0.36	0.32	0.30	0.30	0.28	0.36	1.26	1.24	1.16	1.28	1.29	1.26
10	1	28.00	1.06	0.94	0.98	1.00	1.13	1.18	0.16	0.24	0.24	0.20	0.24	0.26	1.22	1.18	1.22	1.20	1.37	1.44
11	1	18.50	0.84	0.84	0.94	0.94	1.12	1.16	0.24	0.26	0.26	0.26	0.22	0.28	1.08	1.10	1.20	1.20	1.34	1.44
12	2	23.00	1.02	0.98	1.15	1.08	1.12	1.20	0.12	0.18	0.14	0.14	0.20	0.18	1.14	1.16	1.27	1.22	1.32	1.38
13	2	19.00	0.76	0.84	0.90	0.90	1.18	1.16	0.20	0.24	0.32	0.28	0.20	0.24	0.96	1.08	1.22	1.18	1.38	1.40
14	2	18.50	0.88	0.82	0.98	0.98	1.13	1.02	0.28	0.26	0.28	0.32	0.30	0.28	1.16	1.08	1.26	1.30	1.43	1.30
15	2	21.50	0.92	0.90	0.96	0.96	1.14	1.12	0.34	0.30	0.34	0.32	0.32	0.32	1.26	1.20	1.30	1.28	1.46	1.44
16	2	19.25	1.00	0.94	0.96	0.87	1.24	1.24	0.22	0.24	0.22	0.20	0.24	0.24	1.22	1.18	1.18	1.07	1.48	1.48
17	2	19.75	0.92	0.86	0.94	0.93	1.20	1.24	0.32	0.34	0.38	0.32	0.32	0.36	1.24	1.20	1.32	1.25	1.52	1.60
18	2	18.75	0.90	0.96	0.94	0.84	1.14	1.20	0.18	0.18	0.16	0.16	0.16	0.20	1.08	1.14	1.10	1.00	1.30	1.40
19	2	18.50	0.94	0.92	1.02	1.04	1.24	1.20	0.18	0.16	0.16	0.18	0.16	0.16	1.12	1.08	1.18	1.22	1.40	1.36
20	2	24.25	0.98	0.94	1.00	0.96	1.18	1.19	0.24	0.22	0.20	0.18	0.20	0.22	1.22	1.16	1.20	1.14	1.38	1.41
21	2	18.25	1.12	1.00	1.06	1.10	1.07	1.06	0.24	0.28	0.28	0.24	0.24	0.36	1.36	1.28	1.34	1.34	1.31	1.42
22	2	18.50	0.86	0.86	0.88	0.86	1.06	0.98	0.32	0.28	0.32	0.30	0.30	0.34	1.18	1.14	1.20	1.16	1.36	1.32
23	2	18.75	0.94	0.96	0.98	0.94	1.14	1.22	0.26	0.24	0.30	0.28	0.26	0.24	1.20	1.20	1.28	1.22	1.40	1.46

NO	FDG1	FDG2	FDT1	FDT2	FDS1	FDS2	VG1	VG2	VT1	VT2	VS1	VS2	TAG1	TAG2	TAT1	TAT2	TAS1	TAS2
1	224.1	218.9	267	268.9	253.4	258.5	355.9	364.1	383.7	393.9	362.2	370.7	-17.5	-18.1	-19.5	-20.1	-11.5	-13.1
2	305	289.5	309.9	308.7	302.3	303.4	315	312.2	337.4	341.9	310	312.3	4.9	6.3	-6.3	-5.8	1.3	1.8
3	284.2	283.3	293.6	288.1	281.9	282.7	282.7	298.6	325.4	342.2	295.7	299.1	-2.3	-6.2	-12.9	-12.6	-8.9	-10
4	296.5	299.9	329.3	318.5	307.3	303.7	326.4	307.3	332.5	353.2	322.1	322.6	2.7	5.9	6.4	2.1	2.7	1.5
5	275.8	278.6	298.5	302.9	276.7	282	285.1	283.1	321.9	313.7	277.7	261.6	-3.3	0.7	-5.2	-4.4	1.1	3.6
6	264.2	243.7	277.1	276	279	276.6	288	338.4	345	336.5	317.7	305.3	-4	-18.1	-12	-11.3	-6.2	-4
7	252	261.8	265.5	277.8	261.3	259.9	369.8	364.7	407	383.3	376.2	363	-17.2	-16.5	-19.6	-17.8	-16	-16.3
8	236.1	235.7	274.2	291.4	247.4	250.6	320	303	353.1	328.8	316.6	318.9	-13.4	-11.5	-14	-6	-15.4	-17.9
9	266.4	255.4	271.3	264.2	258	264.2	267.2	265.2	299.8	298.4	275.9	248.1	5.2	5.3	-6.9	-5.1	-2.8	-0.6
10	238.9	260.8	272.8	280	260	265.3	330.6	326.1	335.4	361.6	315.1	286.7	-16.2	9.1	-17.8	-21.1	-13.8	-13
11	272	275.6	283.6	280.9	264	268.3	317.6	321	349.7	359.9	324.4	292.3	-7.9	-3.3	-12.8	-14.6	-9.8	-2.4
12	242.8	246.7	266.6	269.3	257.3	254.7	344.5	330.6	369.3	385.4	339.2	341.8	-19	-16	-21.8	-23.1	-14.1	-16.6
13	248.8	259.2	283.2	291.6	254.2	265	318.5	314.2	290.1	327.9	320.1	317.1	-5.3	-4.9	-4.7	-7.5	-15	-10.1
14	263.6	255.4	282.7	280.7	274	275.6	312.6	304.8	335.3	324.7	288.6	320.5	-1.5	-3.4	-6.7	-1.8	2.6	-0.8
15	313.5	296.4	313.4	328.8	309.6	303.3	344.5	344.8	344.4	372.5	336.2	329.2	-0.2	-3.3	-7.6	-9.3	-3	1.7
16	260.7	265.3	270.4	271.8	270.1	264.9	323.6	319.7	375.4	389.4	323.4	313.5	-10.4	-10.5	-20.7	-18.3	-14.3	-12.2
17	298.9	308.9	323.2	313	308.2	316.6	313.2	306.7	328.8	350.7	335	336.5	1.1	1.1	-1.5	-7.6	-1.4	1.4
18	237	235.4	237.6	243.8	237.8	244.7	297.7	299.7	336	353.1	333.4	325.2	-12.7	-16.4	-20.1	-19.6	-18.4	-15.4
19	241.9	241.3	241.1	250.6	241.7	235.8	317	311.1	336.9	341.6	332.1	323.9	-15.8	-16.7	-20	-20.9	-16.7	-17.4
20	236.4	239.1	242.2	243.7	241.9	244.9	253.7	275	307.1	323.5	301.4	280.3	-9.4	-9.9	-20	-21.5	-18	-14.4
21	271.1	279	268.4	280.8	270.5	292.7	320.5	303.8	284.4	325.3	319.1	295.8	-12.6	-10	-15.4	-21.1	-15.8	-1.6
22	277.6	270.1	294.7	293.2	286.2	286.3	284.7	292.3	339.1	333.7	305.9	295.3	-1.9	-4.5	-5	-5.8	-4.4	1.7
23	285.5	274.4	309.5	320.3	282.1	282.1	341.8	337.9	345.1	376.9	336.9	360.8	-5.9	-6.3	-6.8	-12.8	-8.3	-12

NO	EAG1	EAG2	EAT1	EAT2	EAS1	EAS2	HIFG1	HIFG2	HIFT1	HIFT2	HIS1	HIS2	HIHG1	HIHG2	HIHT1	HIHT2	HIG1	HIG2
1	40	39.4	49.2	41.4	39	45.1	160	156.5	144.8	149.4	176.3	168.8	9.6	23.2	33.4	33.9	169.6	179.7
2	25.4	30.9	27.7	29.3	30.8	27.1	142.5	137.8	102.2	107	153.1	170.6	12.7	14.8	82.3	84	155.2	152.6
3	32.2	36	35.3	32.9	30.9	32.7	170.6	180.8	98.9	93.5	198.6	207	1.6	3.6	72.3	68.3	172.2	184.4
4	38.5	40.5	35.5	44.9	37.3	32.6	159.2	143.2	153.1	140.9	187.7	188.6	3.1	8.7	50.6	69.1	162.3	151.9
5	53.8	54.9	48.8	44.8	44	54.6	171	156.2	126.8	127.2	180	184.7	11.4	10.7	106.8	90	182.4	166.9
6	55.2	41	51.9	53.5	48.8	50.6	180.5	200	145.6	150.2	191.5	186	9.4	7.2	97.1	95.7	189.9	207.2
7	41.2	36.6	35.1	38.1	34.7	39.7	165	168	146.1	158.8	201	202	5.6	7.9	123.9	66.1	170.6	175.9
8	43.4	43.3	45.4	44.2	42.5	38	192.4	191.7	132	129.7	216	203	2.4	0	61.4	54.7	194.8	191.7
9	39	49.8	37.5	42.6	41.1	35.9	145.4	181.3	94.5	81.2	163.2	165	7.9	0.2	77.8	111.7	153.3	181.5
10	44.7	39.5	36.5	40	38.4	33.2	154.8	173.2	123.4	121.9	191.6	201	26.3	22.6	62	66.7	181.1	195.8
11	36.3	39.8	39.7	40.3	33.4	37.9	188.4	180.3	135.3	125	195.2	196.7	0	0.4	61.4	86.6	188.4	180.7
12	40.6	44	46.7	43	46.7	43.2	202	213	131.7	139.1	226	249	8.7	7.3	63.2	78.7	210.7	220.3
13	50.7	39.9	47.7	48.8	37.2	39.5	159.8	140.2	107.8	121.3	150.8	171.1	8.1	27.8	53.9	65.8	167.9	168
14	40.1	43.8	40.5	43	38.8	39.8	158.7	155.8	106.7	98.9	178	195	18.2	19.4	39.7	48.6	176.9	175.2
15	37.9	41.1	30.9	25.7	32.8	36.2	195.7	209	111	109.2	202	200	-12.3	-27.2	140.6	147	183.4	181.8
16	26.2	29.5	22.8	24.8	32.8	30.9	170.4	154.3	190.8	171.8	259	218	22.5	28.8	75.4	67.2	192.9	183.1
17	30.9	27.4	32	31.6	23.8	24.7	200	213	130.8	132.4	197.8	213	1.6	1.3	53	69.4	201.6	214.3
18	39.1	35.5	37.6	35.2	36.3	35	179	173	155.5	153.8	198.1	197.3	0	0	9.5	14.5	179	173
19	38.9	49.1	42.2	41.3	40.8	40.9	157.6	155.8	125.9	116.7	214	195.6	6.3	8.4	79.8	87.4	163.9	164.2
20	48.1	47.9	46.8	41.5	45.6	46.5	178.2	190.6	92.8	109.8	190.8	185.4	0	0	76.3	53.4	178.2	190.6
21	29.8	24.4	36.6	33	26.4	27.1	189	187.8	133.1	134.3	209	211	1.1	0.8	21.4	40.1	190.1	188.6
22	43.7	47.9	47	51.5	34.4	47.4	159.4	196.5	168.4	158	202	201.4	-12.8	-20	59.7	52	146.6	176.5
23	23.6	31.9	36.3	31.5	25.8	29.8	174.2	212	138	131.5	226	243	15.8	0	77.6	100	190	212

NO	HIT1	HIT2	HFFG1	HFFG2	HFFT1	HFFT2	HFS1	HFS2	HFHG1	HFHG2	HFHT1	HFHT2	HFG1	HFG2	HFT1	HFT2	VIG1	VIG2
1	178.2	183.3	537	549	432	415	703	720	36.7	58.3	113.3	113.4	573.7	607.3	545.3	528.4	17.3	1.7
2	184.5	191	554	540	317	330	671	630	40.6	58.3	208.3	212.8	594.6	598.3	525.3	542.8	58.8	79.8
3	171.2	161.8	615	610	330	293	740	781	25.1	51.4	147.4	168.2	640.1	661.4	477.4	461.2	65.4	38.9
4	203.7	210	623	566	417	386	723	701	19.7	37.2	126	155.8	642.7	603.2	543	541.8	158.2	110.3
5	233.6	217.2	593	645	405	413	674	686	38.7	36.1	252.3	247.3	631.7	681.1	657.3	660.3	83.6	66
6	242.7	245.9	571	627	386	349	750	718	28.5	29.1	227.6	226	599.5	656.1	613.6	575	85	47.7
7	270	224.9	601	583	366	393	725	713	33.2	31.3	287.9	211.4	634.2	614.3	653.9	604.4	39.9	35.8
8	193.4	184.4	627	596	413	447	842	857	7.7	0.5	174.3	179.3	634.7	596.5	587.3	626.3	47.3	66.1
9	172.3	192.9	527	527	291	239	649	632	28.2	6.1	207.8	277.9	555.2	533.1	498.8	516.9	30	78.6
10	185.4	188.6	554	564	320	273	673	542	79.7	71.5	154.8	219.2	633.7	635.5	474.8	492.2	53.5	73.7
11	196.7	211.6	571	613	378	371	688	652	-0.1	6.7	184.9	247.8	570.9	619.7	562.9	618.8	24.7	39.3
12	194.9	217.8	647	667	405	402	784	754	24.8	24.2	171.4	222.1	671.8	691.2	576.4	624.1	17.6	3.3
13	161.7	187.1	637	591	295	347	728	776	39.8	99.9	170.3	184	676.8	690.9	465.3	531	48.3	77.9
14	146.4	147.5	559	576	371	305	771	776	80.2	124.2	119.4	155	639.2	700.2	490.4	460	113.9	114.1
15	251.6	256.2	691	703	417	376	837	918	-5.4	-1.1	376.2	413	685.6	701.9	793.2	789	117	113.2
16	266.2	239	608	567	393	383	627	637	53.4	75.9	175.4	171.1	661.4	642.9	568.4	554.1	34.9	50.5
17	183.8	201.8	652	625	371	344	845	776	7.9	6.6	158.4	201.5	659.9	631.6	529.4	545.5	31.9	48.3
18	165	168.3	630	547	364	403	801	762	0.3	0	31.1	57.2	630.3	547	395.1	460.2	44	40
19	205.7	204.1	591	530	300	305	767	791	31.9	36.9	214.4	206.5	622.9	566.9	514.4	511.5	62.8	56.4
20	169.1	163.2	537	583	266	322	776	708	0	0	168.5	133.4	537	583	434.5	455.4	46.7	46.7
21	154.5	174.4	549	571	320	378	701	693	4.8	4	76.2	136.6	553.8	575	396.2	514.6	11.5	8.9
22	228.1	210	684	723	391	432	864	850	-2.6	-5	186.4	168	681.4	718	577.4	600	105.4	106.4
23	215.6	231.5	740	747	427	437	920	876	47.4	-58.1	218.3	281.9	787.4	688.9	645.3	718.9	51.1	52.5

NO	VIT1	VIT2	VIS1	VIS2	VIHG 1	VIHG 2	VIHT1	VIHT2	VFG1	VFG2	VFT1	VFT2	VFS1	VFS2	VFHG1	VFHG2	VFHT1	VFHT2	HTG1	HTG2	HTT1	HTT2
1	47.9	43	95.4	93.6	49.5	98.6	62.6	69	117.5	21.1	196.2	192.9	467	472	177.3	213.2	212.8	219.6	0.41	0.6	0.52	0.52
2	53.9	39	114.9	111.8	186.7	202.5	190.1	178.3	226	323	227	215	484	413	449	523	440	429	0.67	0.63	0.64	0.6
3	104.8	116	105.3	117.1	157.5	127.3	211.9	240.3	248	167	327	398	391	476	398.3	331.4	439.6	542	0.61	0.58	0.8	0.78
4	80.6	67.1	138	125.1	212.3	204.4	154.4	205	482	399	231	179.1	531	511	539	507	384	467	0.7	0.64	0.65	0.68
5	96.8	87.5	105.3	106.7	310.3	352.1	336	274.5	326	290	386	367	474	509	716.2	739	785	726	0.64	0.65	0.61	0.58
6	79.4	87.7	102.4	126.5	75.5	177.8	194.8	182.7	376	298	311	262	562	565	252	452	458	434	0.6	0.6	0.66	0.66
7	108.1	29.2	80.5	89	168.3	157.6	254.9	133.7	198.9	182.4	349	167	370	352	468	412	551	424.3	0.61	0.65	0.71	0.5
8	115.3	94.1	103.1	101.9	194.6	173.1	281.7	260.7	241	337	408	406	508	641	456	453	633	712	0.69	0.6	0.69	0.56
9	66	99.1	91.1	90.5	140.5	198.8	185.4	234.8	176.9	197.8	260	376	491	567	298.7	387.7	486	570	0.58	0.73	0.57	0.71
10	20.4	82.9	64.3	94.6	168	185.7	146.6	166.5	249	304	138.5	393	392	432	444	507	363.6	477	0.6	0.6	0.59	0.66
11	62.4	61.4	74.7	75.7	37.2	75.6	151.3	183.7	205	196.2	259	262	296	358	187.9	291.3	424	472	0.39	0.44	0.6	0.59
12	69	81.4	80.9	102.6	113.7	53.9	143.5	180.6	99.8	28.8	272	316	301	293	249.3	155.3	380.1	456	0.64	0.52	0.65	0.66
13	65.3	80.2	102.8	107.6	199.2	271.4	148.1	190.2	264	378	280	267	544	616	590	725	466	397.2	0.51	0.57	0.5	0.62
14	134.2	112.3	128.7	121.8	104.9	82.4	124.9	110	642	699	522	511	836	790	261	277.2	347.3	332.2	0.75	0.7	0.84	0.83
15	163.5	157.5	142.7	153.5	193.5	212.9	364.6	400	305	381	605	609	651	809	462	505	875	912	0.63	0.62	0.66	0.68
16	65.2	44.7	71.9	80.4	186.9	231.9	180.4	177.7	121.9	194.5	214	181.3	361	376	324.6	479	413.2	438	0.73	0.66	0.66	0.58
17	77.6	62.8	144.6	137.8	82	100.9	124.4	176.4	308	267	283	283	740	662	248.6	294.5	358.7	480	0.5	0.52	0.58	0.6
18	58.8	26.9	58.2	67.6	41.8	68.8	93.1	87.5	219	168.1	160.4	139.5	268	323	138.2	224.9	279	296.1	0.47	0.57	0.64	0.51
19	87.4	68.5	105.5	92.1	179.3	192.9	189.1	199.7	272	259	318	272	573	463	479	518	480	457	0.62	0.6	0.7	0.74
20	82.7	91.7	101.5	113.7	134.1	177.7	294.2	305.5	220	233	300	377	550	505	363.1	456	601	689	0.66	0.66	0.73	0.7
21	29.5	35.7	73.5	98.6	40.9	53.7	60.4	94.5	87.9	59.3	162.6	178	367	382	122.3	208.6	213	323.2	0.44	0.38	0.4	0.45
22	59.1	81	101.6	116.1	181.3	146.2	201.5	166.8	410	482	288	356	602	654	602	545	591	511	0.49	0.49	0.52	0.52
23	130.7	135	121.9	110	260.2	192.8	211.3	283.7	242	208	402	486	469	428	615	476	523	660	0.62	0.62	0.69	0.67

Post-test Raw Data

NO.	GRP	BTG1	BTG2	BTT1	BTT2	BTS1	BTS2	FTG1	FTG2	FTT1	FTT2	FTS1	FTS2	TTG1	TTG2	TTT1	TTT2
1	1	0.88	0.78	0.90	0.80	1.18	1.14	0.14	0.16	0.28	0.24	0.24	0.24	1.06	0.90	1.18	1.04
2	1	1.00	0.94	1.00	0.96	1.22	1.16	0.34	0.32	0.32	0.36	0.42	0.38	1.34	1.26	1.32	1.32
3	1	0.92	0.90	0.96	0.92	1.18	1.24	0.36	0.36	0.34	0.32	0.36	0.34	1.28	1.26	1.30	1.24
4	1	1.08	0.98	0.96	0.96	1.16	1.22	0.38	0.36	0.38	0.40	0.36	0.38	1.56	1.34	1.34	1.36
5	1	0.96	0.94	0.90	0.92	1.02	1.02	0.32	0.30	0.34	0.34	0.34	0.36	1.28	1.24	1.24	1.26
6	1	1.02	1.06	0.98	1.04	1.28	1.24	0.32	0.28	0.28	0.24	0.30	0.30	1.34	1.34	1.26	1.28
7	1	1.00	1.02	1.10	0.98	1.20	1.22	0.14	0.18	0.16	0.20	0.16	0.18	1.14	1.20	1.26	1.14
8	1	0.98	0.96	1.04	1.04	1.14	1.26	0.24	0.22	0.22	0.18	0.18	0.26	1.22	1.12	1.26	1.22
9	1	0.78	0.82	0.78	0.80	0.92	0.96	0.32	0.36	0.36	0.34	0.34	0.32	1.10	1.18	1.14	1.14
10	1	1.10	1.14	0.96	0.98	1.16	1.20	0.20	0.20	0.24	0.22	0.22	0.18	1.36	1.34	1.20	1.20
11	1	0.82	0.90	0.80	0.82	1.26	1.34	0.24	0.30	0.32	0.28	0.28	0.30	1.06	1.20	1.12	1.10
12	2	1.00	1.02	0.94	0.92	1.24	1.28	0.18	0.16	0.24	0.18	0.20	0.24	1.18	1.18	1.18	1.10
13	2	0.98	0.84	0.88	0.88	1.24	1.14	0.26	0.34	0.32	0.30	0.34	0.32	1.24	1.20	1.20	1.18
14	2	1.02	0.88	0.88	0.86	1.04	0.96	0.28	0.26	0.34	0.24	0.28	0.26	1.30	1.14	1.22	1.10
15	2	0.88	0.80	0.96	1.00	1.32	1.32	0.42	0.38	0.36	0.44	0.40	0.38	1.30	1.18	1.32	1.44
16	2	1.00	0.90	0.94	1.02	1.24	1.18	0.24	0.32	0.26	0.32	0.26	0.24	1.24	1.22	1.20	1.34
17	2	0.94	0.96	1.02	1.02	1.38	1.36	0.42	0.36	0.36	0.38	0.38	0.40	1.36	1.32	1.38	1.40
18	2	0.94	0.98	0.90	0.94	1.20	1.24	0.14	0.16	0.18	0.14	0.22	0.18	1.08	1.14	1.08	1.08
19	2	1.00	1.02	1.02	1.00	1.36	1.22	0.16	0.24	0.26	0.22	0.22	0.26	1.16	1.26	1.28	1.22
20	2	0.90	0.92	0.88	0.84	1.14	1.20	0.20	0.20	0.24	0.22	0.22	0.26	1.10	1.12	1.12	1.06
21	2	0.98	0.90	1.10	1.04	1.12	1.08	0.26	0.32	0.32	0.28	0.36	0.32	1.24	1.22	1.42	1.32
22	2	0.96	0.84	0.74	0.82	1.12	1.20	0.34	0.34	0.36	0.36	0.32	0.36	1.30	1.18	1.10	1.18
23	2	0.98	1.06	0.92	0.90	1.48	1.32	0.30	0.24	0.24	0.22	0.22	0.24	1.28	1.30	1.16	1.12

TTS1	TTS2	FDG1	FDG2	FDT1	FDT2	FDS1	FDS2	VG1	VG2	VT1	VT2	VS1	VS2	TAG1	TAG2	TAT1	TAT2	TAS1	TAS2
1.42	1.38	235	237	278	276	268	274	345.7	362.5	379.8	386	376.1	374.6	-13.2	-14.1	-19.3	-17.9	-11.5	-10.3
1.64	1.54	289	289	294	310	304	302	312.4	295.2	287.6	340.1	302.5	310.3	4.6	3.2	-4.8	-2.7	1.3	1.7
1.54	1.58	285	283	282	280	292	288	291.9	279.4	311.2	301.5	311.2	300.6	-5.7	-2.1	-14.7	-12.3	-9.9	-9.1
1.52	1.60	299	295	300	314	314	314	319.4	301	309.8	333.5	313.9	324.5	3.9	5	3.9	5.1	2.2	3
1.36	1.38	286	280	324	321	284	294	294.1	259.6	338.5	322.6	267.7	280.1	-1.4	-2.3	-4.8	-4.1	2.1	1.7
1.58	1.54	265	259	272	258	264	260	311.3	299.9	330.4	297.8	296.4	291.3	-13.7	-9.3	-10.8	-12.6	-4.1	-4.9
1.36	1.40	255	263	272	294	258	262	342.2	360.1	382.7	401.2	370.8	363.4	-15.8	-17.2	-19.8	-18.4	-18.8	-17.1
1.32	1.40	239	239	242	238	248	260	318.3	302.7	309.5	298.7	315.6	336.7	-13.8	-9.5	-9.6	-8.8	-14.8	-12.6
1.26	1.28	255	265	280	274	270	256	260.5	280.5	330.1	311.2	273.2	260	6.1	3.7	-4.8	-4.1	-0.2	-1
1.38	1.38	243	249	260	268	246	234	301.2	318.8	319.8	336.4	279.4	269.7	-2.6	-7.3	-19.9	-19.3	-8.6	-10.9
1.54	1.64	259	275	292	282	262	278	280.5	323.7	360.1	338.7	301.2	330.6	-3.9	-6.7	-11.3	-12.9	-7.2	-6.1
1.44	1.52	239	238	270	254	260	270	329.5	338.3	380.5	354	341.5	366.7	-15.4	-17.1	-15.3	-18	-16.9	-15.1
1.58	1.46	271	284	288	284	296	286	331.3	349.9	315.6	298.8	369.7	354.8	-5.7	-2.1	-4.1	-4.6	-8.2	-9.5
1.32	1.22	247	251	284	278	272	254	300.5	317.7	341.1	322.6	304.2	280.1	2	-0.6	-4.2	-3.4	3.4	1.1
1.72	1.70	309	322	328	354	328	336	360.4	378.2	358.7	396.5	368.8	370.4	-0.8	-2.1	-4	-5.1	0.4	1.3
1.50	1.42	245	256	275	288	256	260	310	335.5	379.4	396.7	299	310.7	-12.8	-8.3	-12.8	-15.8	-10.8	-9.5
1.76	1.76	327	320	336	334	324	338	344.6	335.3	360.3	369.8	355.3	369.4	1.2	-0.3	-2.8	-3.7	-0.6	1.2
1.42	1.42	227	232	256	240	264	248	277.7	289.6	369.9	342	356.5	333.5	-15.1	-12.4	-12.9	-15.3	-16.8	-17.5
1.58	1.46	225	244	260	264	246	252	284.6	317	366.2	364.5	351.4	361.7	-15.3	-16.7	-17.8	-14.6	-12.1	-14.8
1.36	1.46	213	210	241	237	220	230	241.1	237	317.7	309.6	267.6	277.2	-7.7	-8.5	-15.3	-13.9	-12.7	-10.5
1.48	1.44	271	283	297	283	296	310	309.8	319.8	341.8	319.2	331.9	349.8	-10.1	-8.3	-13.5	-15.1	-7.1	-6
1.44	1.56	283	270	302	286	258	284	300.2	286.3	345.5	322.8	267	299.1	-2.2	-2.5	-2.9	-4.2	0.6	-0.3
1.70	1.56	304	284	299	296	288	292	354.5	329.4	334.9	341.2	364.1	362.3	-11.2	-9.9	-10.8	-12.1	-9.9	-11.4

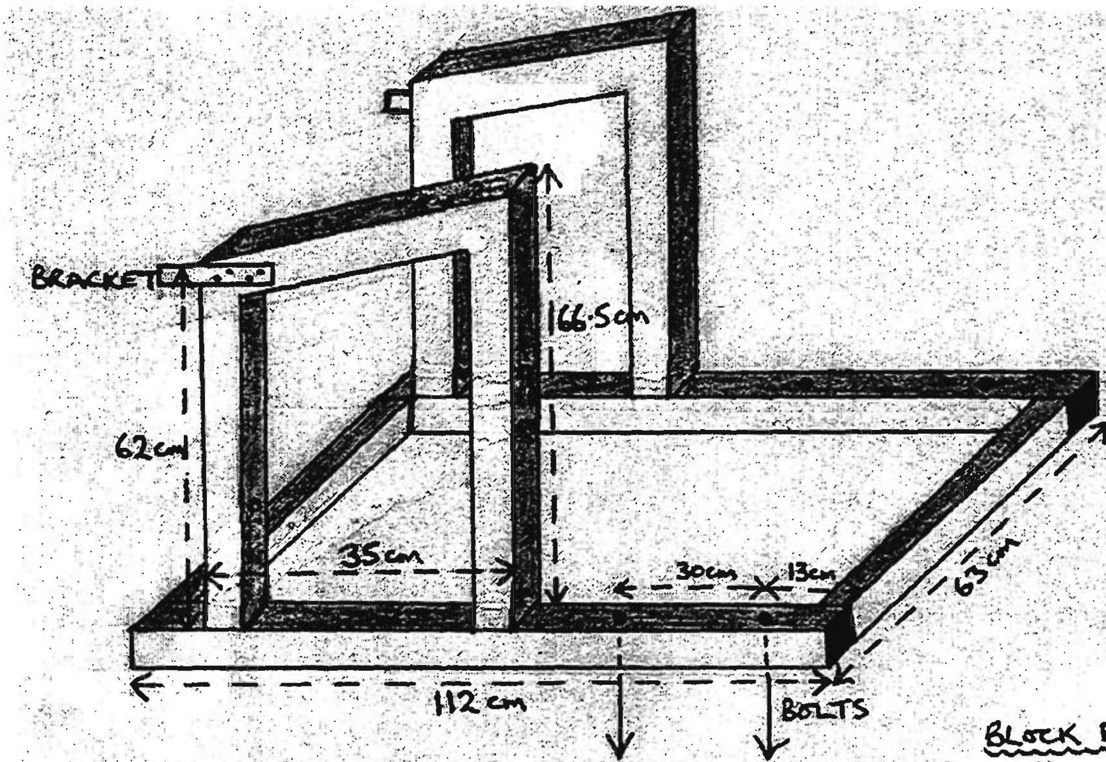
NO	EAG1	EAG2	EAT1	EAT2	EAS1	EAS2	HIG1	HIG2	HIT1	HIT2	HIS1	HIS2	HIFG1	HIFG2	HIFT1	HIFT2	HIHG1	HIHG2	HIHT1	HIHT2
1	42.4	41.8	46.1	48.3	49.1	45.4	166	163.5	201.1	211.9	171.4	170.7	150.1	148.5	144.1	148.3	15.9	15	57	63.6
2	30	28.9	29.1	30.6	31.9	30.3	153.8	148.2	217.6	217.3	154.3	154.1	136.3	136.4	111.3	106.4	17.5	11.8	106.3	110.9
3	35.3	37.1	40.8	42.9	30.8	31.7	173.1	153.4	161.7	174.8	177.1	181	180.4	162.6	88.2	87.3	-7.3	-9.2	73.5	87.5
4	39.8	40.6	44.1	42.2	38.6	41.2	141.6	153.4	225.9	234.1	185.3	183.6	140.2	145	153.1	156.4	1.4	8.4	72.8	77.7
5	52.3	52.9	44.6	45.8	44.5	45.7	177.8	173.3	220.7	221.2	191	186.9	168	162	120.4	129	9.8	11.3	100.3	92.2
6	53.2	47.6	49.7	54.9	51.9	54.1	166.9	180.5	239.6	228.4	191.1	191.4	162.3	183.7	160.1	125.4	4.6	-3.2	79.5	103
7	33.8	34.5	31.5	39.1	32	35.8	168.9	170.4	247.7	243.9	203.8	211.3	156.4	158.3	141.9	149	12.5	12.1	105.8	94.9
8	43.1	45.3	47.8	50.6	41.4	39.6	174.5	162	163.8	184.9	186.5	186.5	161.6	165.1	113.9	122.4	12.9	-3.1	49.9	62.5
9	44.8	40.6	42	44.5	41.9	43.6	154.1	143.8	152.5	162.8	167.1	170.2	157.7	146	88.1	92.8	-3.6	-2.2	64.4	70
10	33	30.2	27.4	30.6	27.1	33.4	172.7	171.6	162.4	181.8	175.3	181.4	163.2	162.4	106.8	111.9	9.5	9.2	55.6	69.9
11	33.4	34.1	31.5	31.8	38.5	32.3	166.2	167.9	150.5	156	178.1	180.6	161.3	166.3	105.1	105	4.9	1.6	45.4	51
12	43.6	39.9	47.3	45.6	30.2	31.8	199.3	203.9	270.8	257.5	212	232	186.2	197.1	174.7	183.5	13.1	6.8	96.1	74
13	43.2	44.8	50.1	43.5	41.6	45.6	165.4	152	220.9	230.8	180.5	167.1	151.2	137.1	116.1	119.7	14.2	14.9	104.8	111.1
14	41.2	44	45.9	45.3	39.7	41.4	151.6	180.6	150.8	192.1	172.7	157.6	138.4	164.9	110.3	119.8	13.2	15.7	40.5	72.3
15	48.9	38.3	38.8	33.2	40.9	42.3	185.4	163.4	310.6	263.3	194.5	207	189.9	166.1	107.8	101.4	-4.5	-2.7	202.8	161.9
16	32.5	31.7	32.6	34	31.1	29.2	172.5	146.2	224.2	225.3	199.1	199.1	158.3	130.2	108.1	98.2	14.2	16	116.1	127.1
17	30.8	35.1	30.7	32.8	30.5	28.9	185.5	228.6	245.4	253.9	215	217	176.4	222	113.3	121.4	9.1	6.6	132.1	132.5
18	32.3	38.8	32.3	33.1	30	30.8	176.2	173.8	198.4	176.3	182.7	201.9	181.9	176.9	144.5	134.5	-5.7	-3.1	53.9	41.8
19	40.7	42.2	44.1	36.7	50.1	39.7	178.6	173.7	238	250.2	199.7	239	162.7	166.2	112.7	121.3	15.9	7.5	125.3	128.9
20	47.6	46.3	49.7	45.6	45.2	41.7	171	162.3	151.7	152.8	157.5	167.9	174.1	164.2	103.5	98.9	-3.1	-1.9	48.2	53.9
21	29.9	31.6	38.1	33.9	33.1	28.7	177.4	171.8	203	193.9	202.3	204	173.2	171.8	129.4	137.7	4.2	0	73.6	56.2
22	45.6	48	45.5	46.8	50.4	44.5	145.8	175.7	193.9	220.4	177.4	183.9	138.7	178.1	143	145.2	7.1	-2.4	50.9	75.2
23	32.4	34	39	30.4	34	32.3	185.1	196.1	221.5	242.6	227	215	183.8	190	137.5	151.6	1.3	6.1	84	91

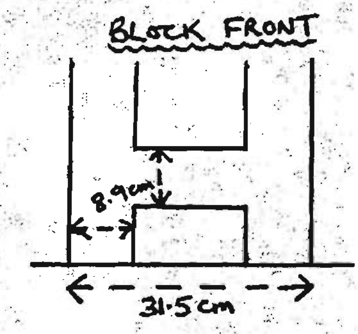
HTG1	HTG2	HTT1	HTT2	HFG1	HFG2	HFT1	HFT2	HFS1	HFS2	HFFG1	HFFG2	HFFT1	HFFT2	HFHG1	HFHG2	HFHT1	HFHT2
0.61	0.54	0.66	0.51	620.4	610.8	521.8	624.9	740	715	588	571	398	479	32.4	39.8	123.8	145.9
0.68	0.62	0.68	0.61	558.3	581.5	510.8	472.5	588	591	520	557	315	278	38.3	24.5	195.8	194.5
0.62	0.61	0.66	0.61	581.7	549.8	444.8	453.1	728	691	564	535	288	283	17.7	14.8	156.8	170.1
0.67	0.65	0.62	0.63	588.7	586.3	526.8	509.4	698	652	562	552	366	366	26.7	34.3	160.8	143.4
0.6	0.64	0.6	0.59	614.2	657.1	647	639.3	669	693	581	623	398	401	33.2	34.1	249	238.3
0.62	0.73	0.62	0.62	584.8	631.3	573.9	605.6	725	740	574	620	393	369	10.8	11.3	180.9	236.6
0.64	0.62	0.64	0.62	628.1	626.2	659	653.4	712	722	589	593	360	401	39.1	33.2	299	252.4
0.67	0.59	0.74	0.72	631.8	711.7	581.5	619	955	964	627	708	376	359	4.8	3.7	205.5	260
0.57	0.59	0.45	0.4	555.5	528.5	494.5	504.4	620	681	542	520	278	271	13.5	8.5	216.5	233.4
0.54	0.69	0.57	0.62	602.6	565.9	421.3	526.6	601	679	581	544	273	337	21.6	21.9	148.3	189.6
0.41	0.54	0.44	0.46	515	579	491.2	509.1	615	596	515	579	334	347	0	0	157.2	162.1
0.65	0.64	0.5	0.5	698.1	700.8	660.3	705.3	852	867	664	691	483	483	34.1	9.8	177.3	222.3
0.66	0.48	0.55	0.47	677	624.1	642.5	559.4	774	789	615	569	381	349	62	55.1	261.5	210.4
0.7	0.74	0.74	0.69	623.6	709.9	470.2	536.4	728	642	562	601	320	349	61.6	108.9	150.2	187.4
0.61	0.47	0.68	0.67	647	667	686	723.8	659	664	647	667	320	361	0	0	366	362.8
0.65	0.61	0.62	0.69	576.5	563.1	483.5	496.6	662	635	527	488	317	259	49.5	75.1	166.5	237.6
0.58	0.63	0.65	0.66	622.2	641.8	576.1	627	754	779	605	618	344	403	17.2	23.8	232.1	224
0.61	0.57	0.54	0.63	601	581	454.9	462.1	708	669	601	581	366	330	0	0	88.9	132.1
0.66	0.66	0.7	0.68	599.5	567.2	571.3	597.5	732	786	566	557	281	317	33.5	10.2	290.3	280.5
0.67	0.71	0.66	0.6	566	535.5	428.9	452	637	686	566	532	310	305	0	3.5	118.9	147
0.4	0.44	0.64	0.5	504.1	527	527.9	501.5	664	647	503	527	371	332	1.1	0	156.9	169.5
0.57	0.5	0.42	0.5	642.9	652	536.2	569.9	786	732	632	652	369	369	10.9	0	167.2	200.9
0.6	0.65	0.61	0.63	734.6	769	738.1	760.3	825	862	723	769	505	469	11.6	0	233.1	291.3

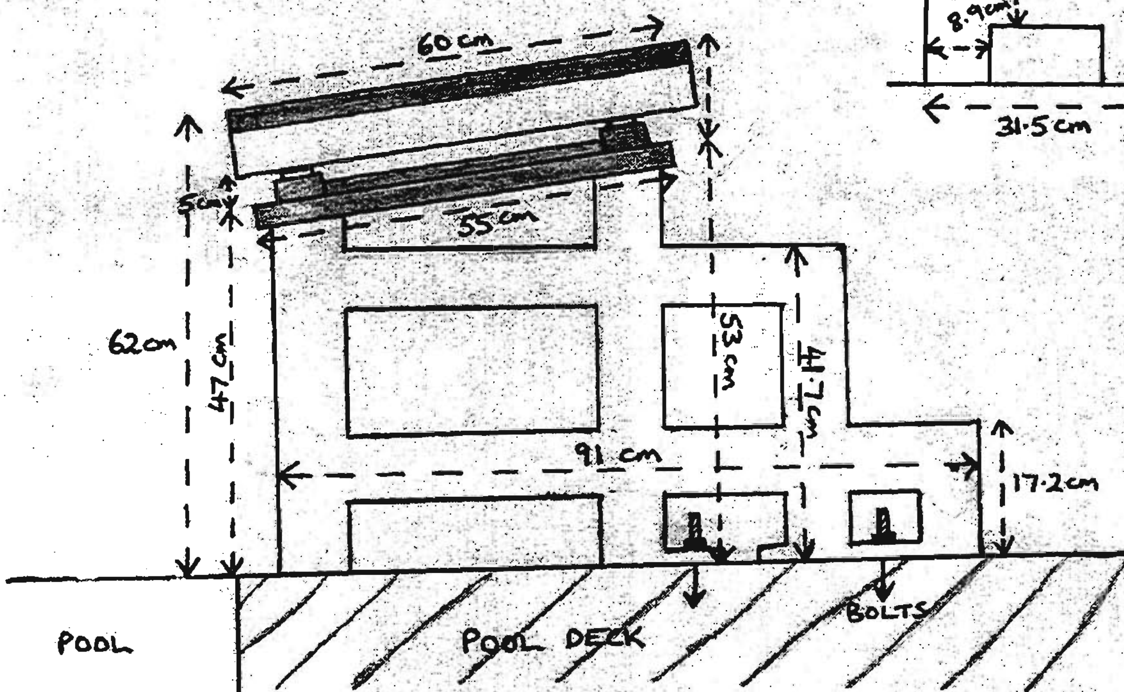
VIFG1	VIFG2	VIFT1	VIFT2	VIFS1	VIFS2	VIHG1	VIHG2	VIHT1	VIHT2	VFFG 1	VFFG 2	VFFT1	VFFT2	VFFS1	VFFS2	VFHG 1	VFHG 2	VFHT1	VFHT2
12.7	29.4	60.1	55.1	129	120	24.7	68.2	118.4	105.1	89	270	142.8	197.8	605	587	55.1	169	276.5	330.3
58.3	74.9	36.7	54.5	140.1	130.6	173.8	232.3	382.9	381.7	210	268	174.7	185.7	582	591	366.3	469	382.9	381.7
99.6	76	106	115.8	145	150.6	219.3	208.4	241.1	265.5	357	292	345	385	624	576	567	481	505	574
150.7	102.9	31.4	61.7	119.1	141.9	222.7	205.1	163.5	233.9	493	386	109.9	223	479	524	542	492	365.9	428.2
88.4	72.8	89.9	90.7	104.9	106.4	313.1	339.7	345	298	309	307	399	372	490	478	697.8	702.3	763	742.6
86	75.5	80.3	83.9	135.2	121.4	109.3	160.2	217.3	278.1	334	398	294	308	636	558	305.8	530.9	457	531
42.6	56.2	67.9	72.1	75	86.9	174.4	169	223.3	201.3	211.6	198.7	289	292	387	365	444	453	534	503
80.2	47.3	132.3	153.9	95.7	124.9	224.5	183.4	314.8	342.3	337	219	416	443	697	881	546	478	659	705
41	83	34.5	62.9	101.3	80.9	186.7	166.3	145.6	156.5	193.4	383	208	348	621	601	446	441	500	589
26.6	39.1	31.6	48.5	31	81.4	71.7	81.4	125.4	172.5	94.5	185.7	154.9	242	161.5	475	201.7	203.3	326.7	437
10.3	19.5	25.3	7.6	101.1	108.3	71.2	131.9	122.8	125.9	134	128.5	131.8	71.4	391	402	272.9	327.5	401	376.8
39.6	34.3	65.2	48.7	81.9	101	209.6	152.3	180.4	239.3	152.7	176.9	278	195.6	286	327	445.6	335.9	485	486
111.1	82.2	73.2	104.1	182	173.9	335.6	287.8	307.7	218.8	493	349	326	385	969	1057	652	652	640	537
95.8	84.4	121.8	137.9	129	128.7	60.8	68.6	96.1	234.4	352	625	565	422	646	633	197.2	208.6	326.7	436
85.1	70.1	169.4	171.7	182	144.6	233.4	219.2	416.6	439	288	322	503	567	744	565	473	551	750	773
70.1	96.6	50.6	77	99.9	105.4	179.8	204.7	196.1	299.3	180.1	259	140.6	246	283	309	302.5	438.3	375.7	475
98.3	78.8	85.9	94.5	184.2	172.1	170.3	133.5	250.6	259.5	370	276	304	325	809	878	408.4	247.1	544	545
45.5	60.8	75.4	98.7	82.2	68.6	113.3	127.1	172.8	217.7	205	234	243	368	333	299	313.3	358.6	436	579
27.7	34.3	76.6	130	123.8	129.7	235.9	170.4	276	289.8	115.4	183.5	321	444	498	563	504	432	625	666
39.9	81.5	100.2	82.3	109	117	202.3	262.3	250.4	260.3	201	280	367	359	545	563	451	560	609	657
29.1	30.6	50.8	40.2	111.3	95.7	86.1	103.6	158.7	130.2	49.4	91.2	216	185.7	488	427	231.6	355.9	384.2	390.5
95.6	65.1	40.7	62.5	161.6	170.6	197.5	157.4	149	187.7	352	261	189	313	691	669	552	523	513	589
67.3	61.9	152.3	97.9	109.1	95.5	177.8	186.7	259	290	240	246	586	439	316	396	498	507	745	720

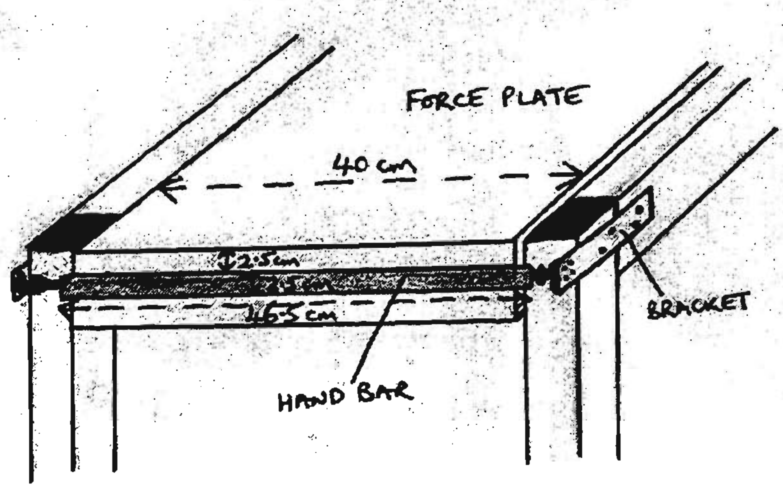
APPENDIX D:

MODIFIED STARTING BLOCK AND FRAME DIMENSIONS


BRACKET
66.5cm
62cm
35cm
30cm
13cm
63cm
112 cm
BOLTS

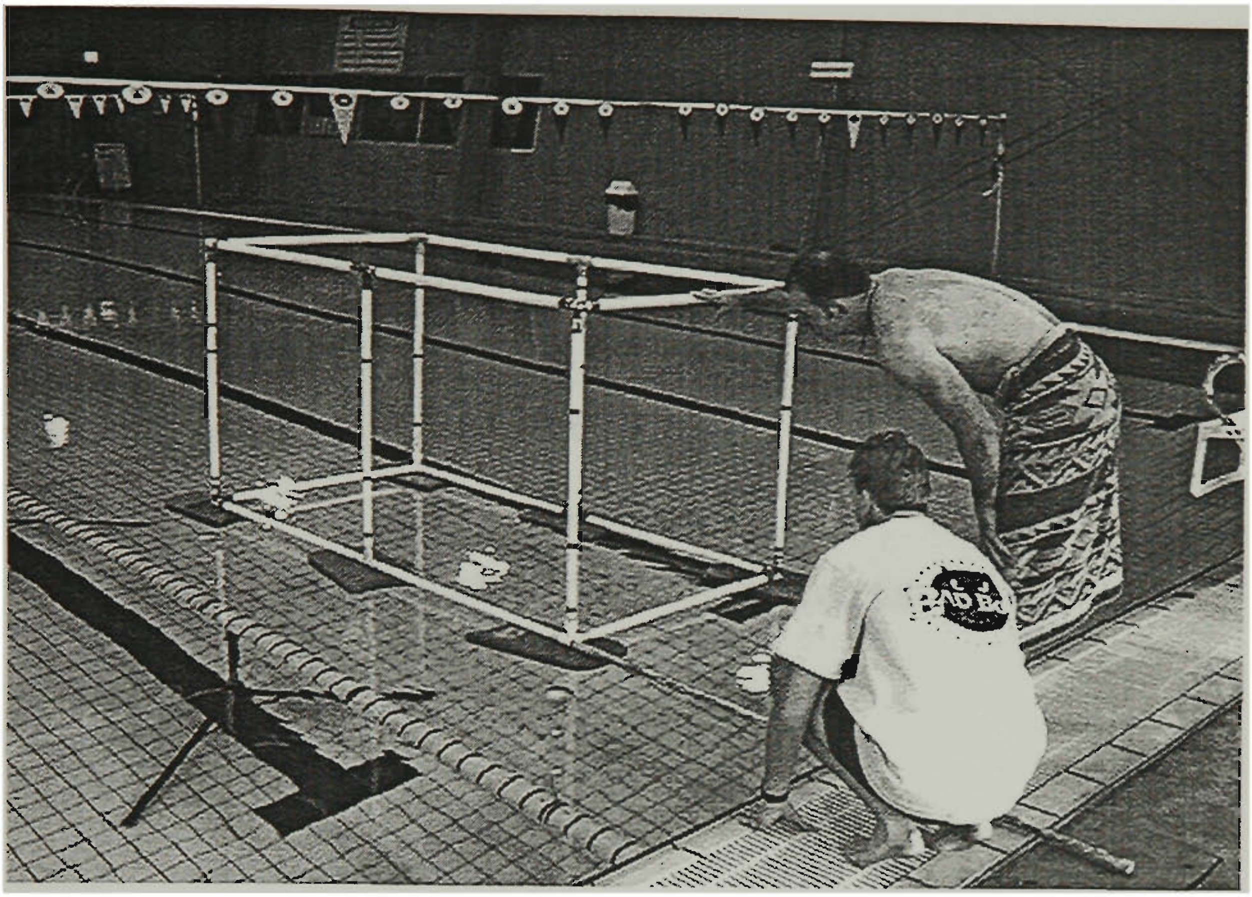

BLOCK FRONT
8.9cm
31.5cm


60 cm
5cm
55cm
62cm
47cm
53cm
41.7cm
91 cm
17.2cm
POOL
POOL DECK
BOLTS


FORCE PLATE
40 cm
2.5cm
46.5cm
BRACKET
HAND BAR

APPENDIX E:

REFERENCE STRUCTURE

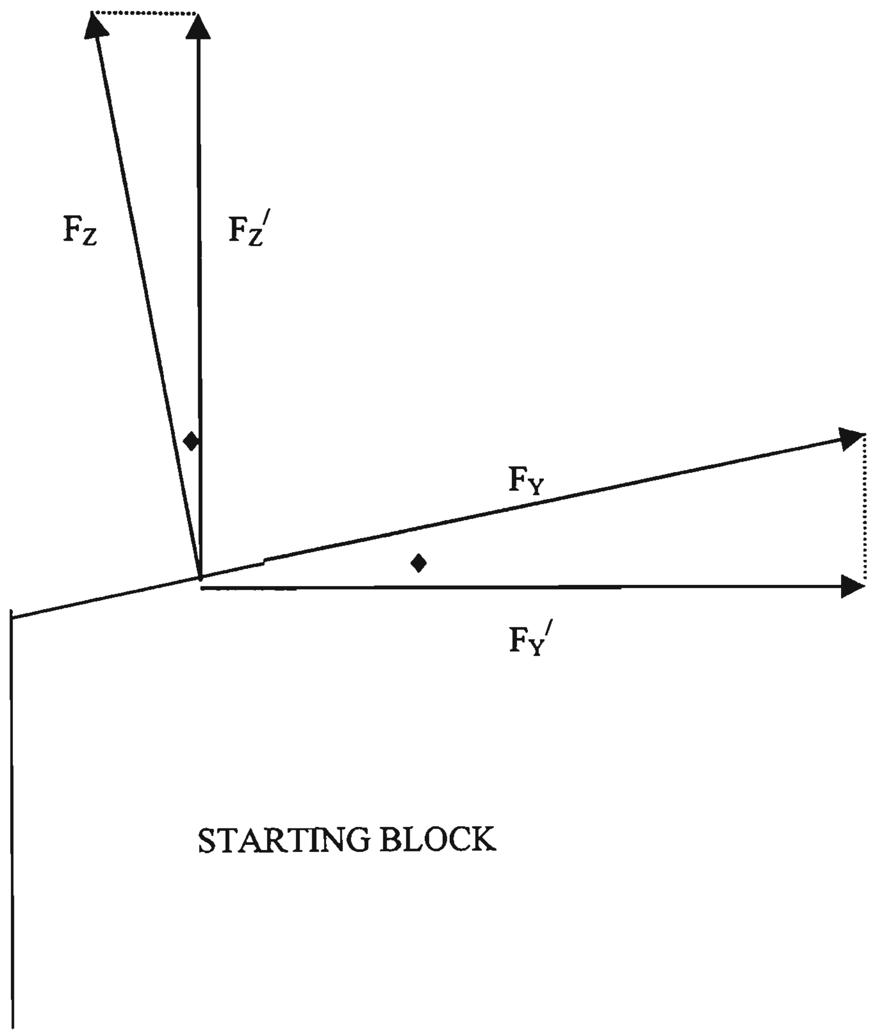


APPENDIX F:

ADJUSTMENT OF FORCE VALUES

$F_Y^{/} = F_Y \cos \blacklozenge + F_Z \sin \blacklozenge$

$F_Z^{/} = -F_Y \sin \blacklozenge + F_Z \cos \blacklozenge$



Where:

F_Y = parallel force to block surface (unadjusted)

$F_Y^{/}$ = true horizontal force (adjusted)

F_Z = perpendicular force to block surface (unadjusted)

$F_Z^{/}$ = true vertical force (adjusted)

When:

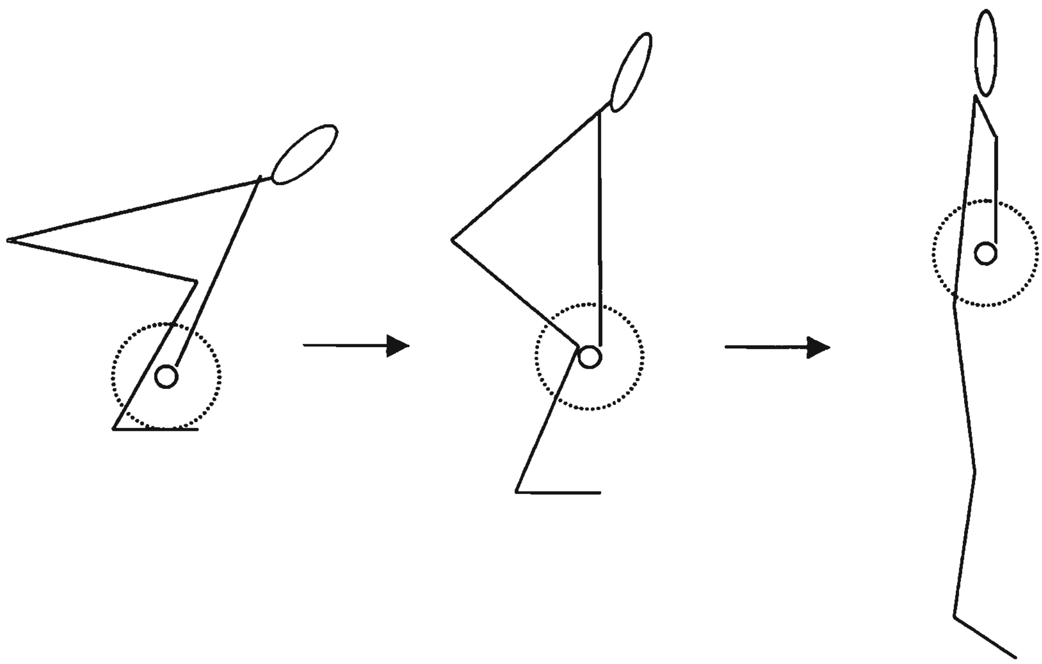
$\blacklozenge = 9^0$

APPENDIX G:

DESCRIPTION OF RESISTANCE TRAINING EXERCISES

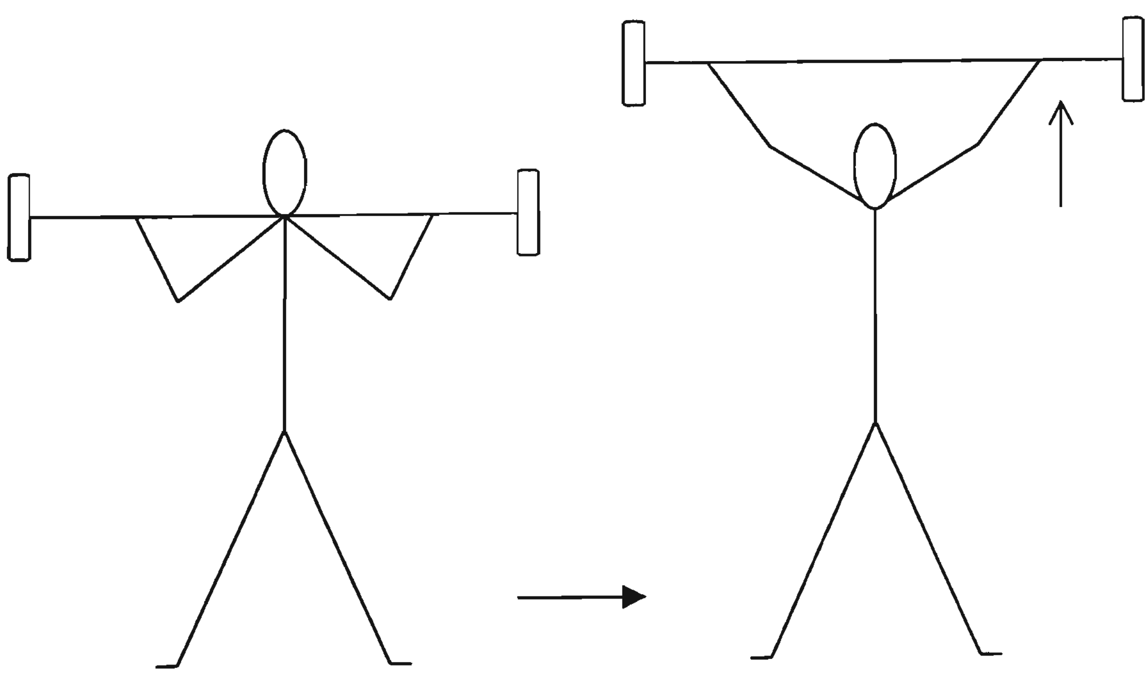
Exercise 1: **Clean Pull**

- Participants place hands on the bar slightly wider than shoulder width apart.
- Feet are slightly less than shoulder width apart with the toes level with the bar.
- The back is straight (no arching), head up and eyes facing straight ahead. The shins almost touch the bar and the body mass is positioned over the heels.
- When ready the bar is lifted explosively straight up to chest height.



Exercise 2: **Barbell Press**

- In a standing position, the barbell is placed across the shoulders behind the head. Hands are positioned so that a 90^0 angle exists at the elbow joints.
- The barbell is pushed explosively upwards to full extension of the arms then lowered slowly.



Exercise 3: **Parallel Squat (Smith machine)**

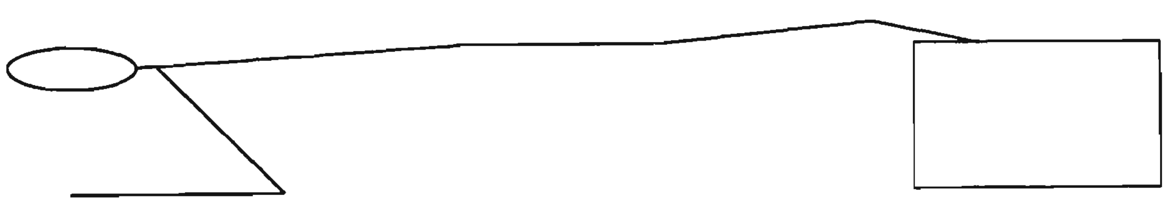
- Stand with the bar across the shoulders with the feet forward of the bar so that the heels are in line with the bar. Feet are shoulder width apart.
- Keeping the back straight (no arching), lower the bar slowly until the thighs are parallel to the ground. Push explosively upwards until the legs are fully extended.

Exercise 4: **Back Extension**

- Crossing the arms to chest, lower and lift the upper body slowly and controlled. If required, hold a weight to the chest.
- Keep the back flat the whole time and only move through a 90^0 range (no hyperextension of the lower back).

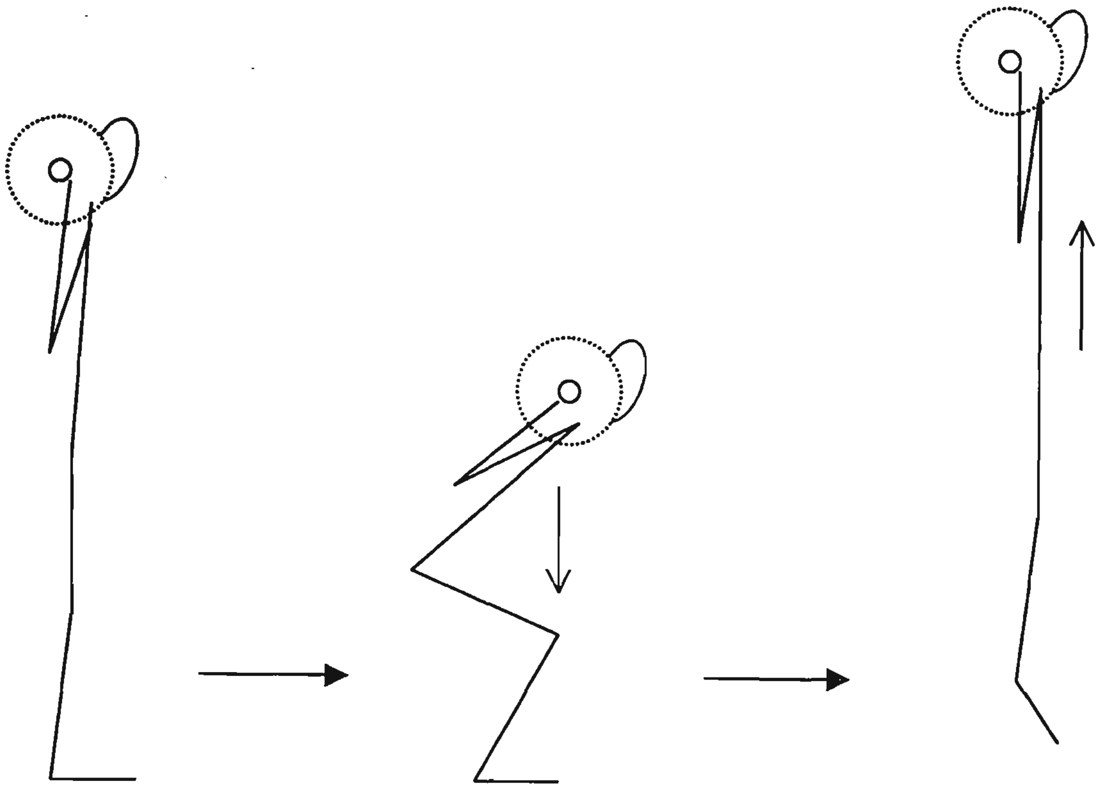
Exercise 5: **Prone Hold**

- An isometric abdominal strengthening exercise. Place feet on a box (30-40cm in height) and lie facing towards the floor.
- Hold the body up off the floor on the elbows. Back stays flat with no arching of the lower back.



Exercise 6: **Barbell Jump Squat**

- The bar is placed across the shoulders (using padding on the bar) and the feet are about shoulder width apart.
- Participants dip down quickly to a knee angle of about 90^0 and then explode immediately upwards to jump as high as possible.
- As they dip down, the heels stay on the ground and the trunk is flexed forwards (about 45^0 to the vertical).
- Repetitions are not continuous (about 2-3 s between each) and are performed maximally.

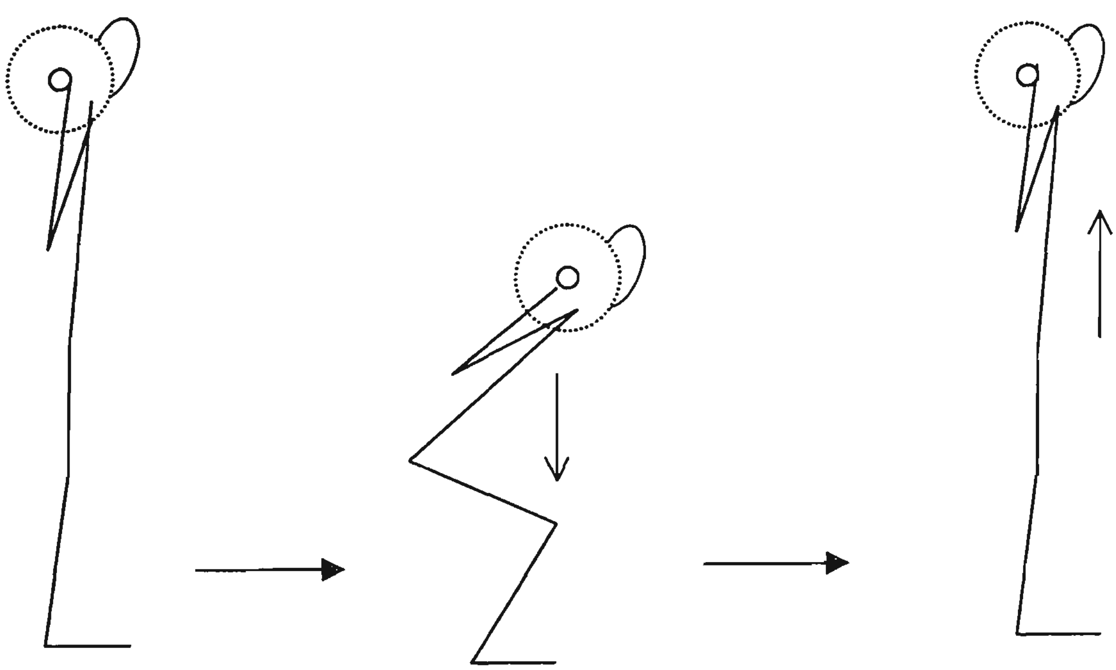


Exercise 7: **Dumbbell Overhead Press**

- In a standing position the dumbbells are held in front of the shoulders level with the neck, and then pushed explosively upwards until arms reach full extension
- Dumbbells are lowered slowly

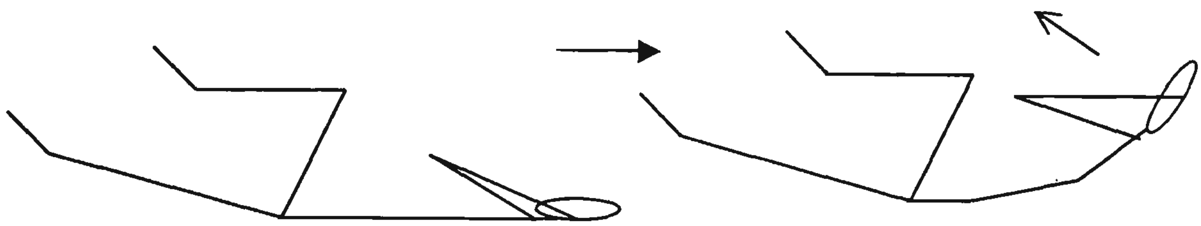
Exercise 8: **Barbell ½ Squat**

- Using a squat rack, the bar is placed across the shoulders and the participant lowers their body slowly until a 90^0 angle at the knee joint is reached. The back stays firm and flat.



Exercise 9: **Twisting Crunch**

- Lie on back with one knee raised so that both the hip and knee joint are at about 90^0 of flexion. The other leg is kept straight whilst it is lifted until the heel is about 6 inches above the ground. This position is held.
- With the fingers lightly touching the side of the head, sit up by bringing the opposite elbow across to the raised knee
- Repeat using the other side (to maximum repetitions)

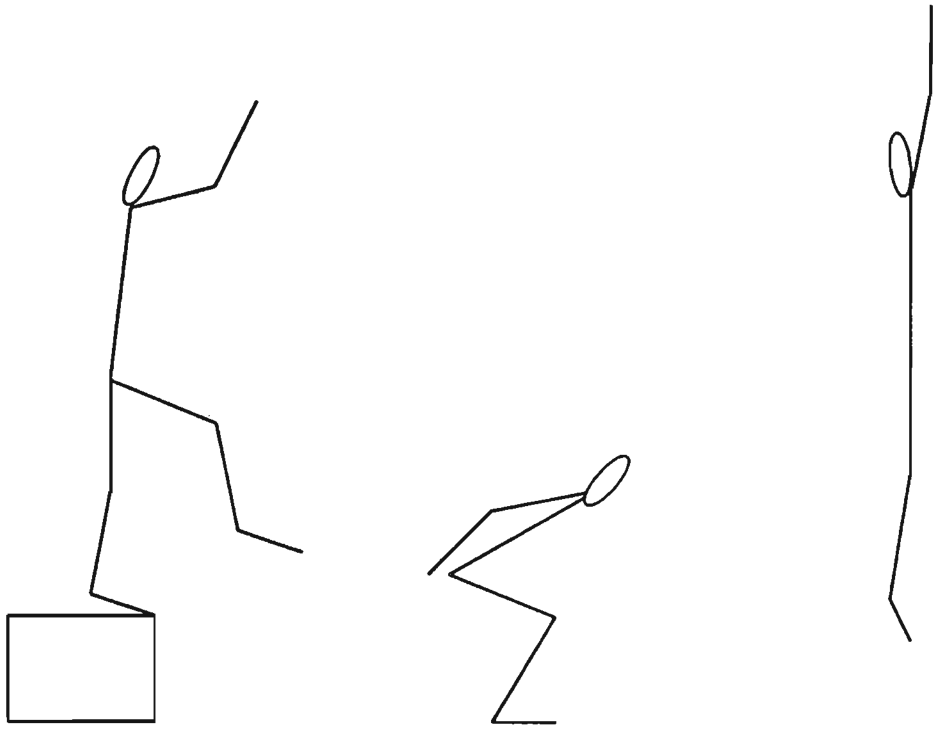


Exercise 10: **Weighted Belt Jump**

- A weight-lifting belt with weights attached to the back is worn.
- A maximal vertical jump using the arms is performed (repetitions are not continuous, 3-5 s break between each).
- A vertical jump board mounted to a wall with horizontal lines at 4 cm intervals is used to provide a motivational target.

Exercise 11: **Drop Jump**

- Participants stand on a wooden box (ranging from 40-60cm)
- Step off the box to land with feet shoulder width apart
- Dip down until the knees are approximately 90^0 then explode up immediately to jump for maximal height
- Use the arms for extra height and coordination



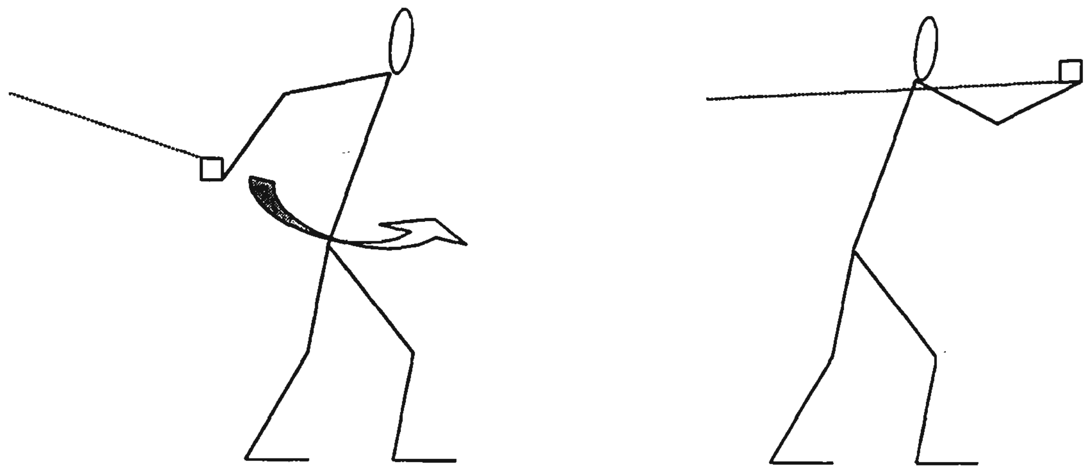
Exercise 12: **Explosive Push-up**

- Begin fully extended in a regular push-up position (or from the knees if not sufficient strength to perform 6 continuous push-ups from the feet)
- Lower body rapidly until the elbows reach approximately 90^0, then explode up immediately to raise the body off the ground quickly. Hands should leave the ground.
- Absorb the impact and then begin the next repetition from full extension after 1-2 s.

(A) (B)

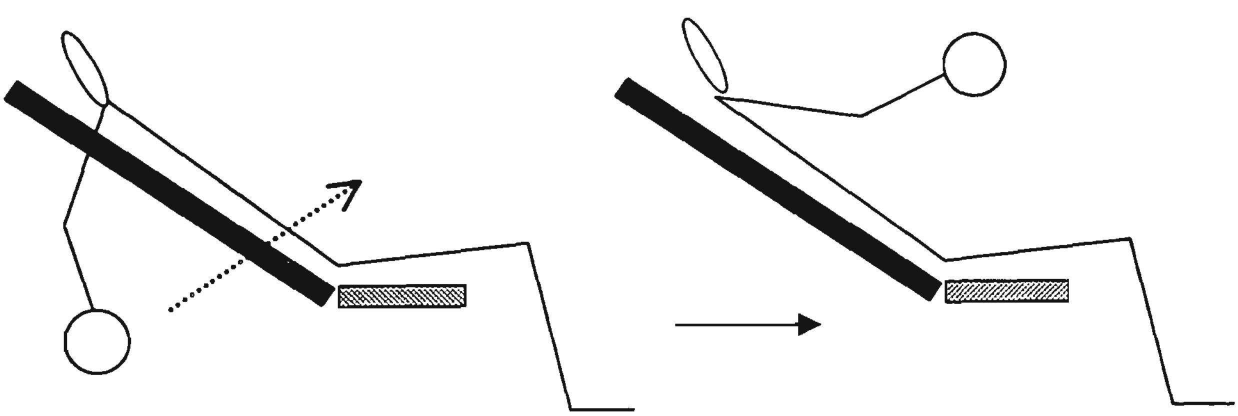
Exercise 13: **Forward Pulley Thrust**

- Using a Universal Gym pulley system, participant stands with a wide split of the feet from front-to-back for balance and control
- Holding both pulley handles, start with elbows behind the body at about 90^0
- Explosively pull handles forward until arms are fully extended in front of the body at shoulder height
- Slowly let weights down to begin the next rep in the same starting position



Exercise 14: **Incline Shoulder Raise**

- Sitting on a bench with the back inclined at 45^0, begin with dumbbells and arms hanging down vertically. Arms should be kept tensed by holding the elbow joint at about 150^0 throughout the whole movement
- Explosively raise the dumbbells together until an angle of approximately 90^0 at the shoulder joint is reached
- Slowly let them back down to the starting position



Exercise 15: **Side Hold**

- Lying on the side, put feet up on a 40cm box whilst supporting body off the ground by leaning on the elbow
- Hold a straight body position to feel stretch along underside of body

APPENDIX H:

PAIRED-SAMPLES STATISTICS

Grab start – Trial 1 and Trial 2

VARIABLE	PAIRED SAMPLES CORRELATIONS		PAIRED SAMPLES TEST	
	correlation	significance	t-value	significance
BT	0.584	0.003	1.845	0.079
FT	0.860	0.000	0.099	0.922
TT	0.720	0.000	1.703	0.103
FD	0.871	0.000	0.380	0.708
V	0.855	0.000	0.089	0.930
TA	0.668	0.000	-0.489	0.630
EA	0.714	0.000	-0.503	0.620
VI	0.811	0.000	-0.070	0.945
HI	0.740	0.000	-1.937	0.066

Track start – Trial 1 and Trial 2

VARIABLE	PAIRED SAMPLES CORRELATIONS		PAIRED SAMPLES TEST	
	correlation	significance	t-value	significance
BT	0.677	0.000	1.531	0.140
FT	0.913	0.000	0.643	0.527
TT	0.786	0.000	1.768	0.091
FD	0.931	0.000	-2.044	0.053
V	0.787	0.000	-2.736	0.012
TA	0.901	0.000	0.940	0.357
EA	0.856	0.000	0.347	0.732
VI	0.686	0.000	0.580	0.570
HI	0.878	0.000	-0.465	0.647

<u>Swing start – Trial 1 and Trial 2</u>

VARIABLE	PAIRED SAMPLES CORRELATIONS		PAIRED SAMPLES TEST	
	correlation	significance	t-value	significance
BT	0.819	0.000	1.035	0.312
FT	0.872	0.000	-2.630	0.015
TT	0.716	0.000	-0.357	0.725
FD	0.936	0.000	-2.087	0.049
V	0.859	0.000	1.927	0.067
TA	0.852	0.000	-2.048	0.053
EA	0.789	0.000	-1.137	0.268
VI	0.859	0.000	-2.110	0.046
HI	0.809	0.000	-0.666	0.512

APPENDIX I:

ANOVA – TEST FOR HOMOGENEITY OF VARIANCES FOR DIVE START VARIABLES

VARIABLE	LEVENE STATISTIC	SIGNIFICANCE
BT	1.1	0.339
FT	0.12	0.887
TT	0.034	0.967
FD	0.099	0.906
V	0.031	0.97
TA	0.025	0.976
EA	0.114	0.893
VI	1.078	0.346
HI	5.463	0.006

APPENDIX J:

LEVENE'S TEST OF EQUALITY OF ERROR VARIANCES FOR DRY-LAND TESTS

VARIABLE	*F* VALUE	SIGNIFICANCE OF *F*
VJ	0.658	0.426
PVJ	1.238	0.278
CMJ	0.488	0.492
PCMJ	2.641	0.119
SQ40	3.816	0.064
PSQ40	5.579	0.028
SQ25	2.839	0.107
PSQ25	1.532	0.229
OT	0.028	0.869
POT	0.114	0.739
OTB	0.015	0.903
POTB	0.044	0.837

KEY:

VJ Vertical jump

CMJ Vertical jump, no arms

SQ40 CES squat, power test

SQ25 CES squat, strength test

OT Overhead throw

OTB Overhead throw, back extension

P Post test

APPENDIX K:

UNIVARIATE REPEATED MEASURES ANOVA – DRY-LAND TESTS

SOURCE	VARIABLE	*F* VALUE	SIGNIFICANCE OF *F*
TIME	VJ	56.752	**0.000**
	CMJ	34.296	**0.000**
	SQ40	11.641	**0.003**
	SQ25	9.433	**0.006**
	OT	2.462	0.132
	OTB	4.288	0.051
TIME BY GROUP	VJ	37.644	**0.000**
	CMJ	26.626	**0.000**
	SQ40	7.891	**0.011**
	SQ25	2.861	0.106
	OT	0.468	0.501
	OTB	0.365	0.552

APPENDIX L:

LEVENE'S TEST OF EQUALITY OF ERROR VARIANCE FOR DIVE START VARIABLES

VARIABLE	GRAB F	Sig of F	TRACK F	Sig of F	SWING F	Sig of F
BT	0.948	0.341	0.001	0.973	1.06	0.315
PBT	4.872	0.039	0.101	0.753	0.266	0.611
FT	4.126	0.055	0.244	0.626	0.16	0.693
PFT	0.055	0.817	0	0.986	0.051	0.824
TT	0.308	0.585	0.073	0.789	1.811	0.193
PTT	5.909	0.024	2.526	0.127	0.05	0.825
FD	0.007	0.935	2.314	0.143	0.978	0.334
PFD	4.261	0.052	0.68	0.419	1.742	0.201
V	0.405	0.531	0.002	0.963	1.389	0.252
PV	0.839	0.37	0.015	0.904	0.232	0.635
TA	1.115	0.303	0.791	0.384	0.003	0.956
PTA	0.29	0.596	0.532	0.474	0.003	0.956
EA	1.178	0.29	1.242	0.278	0.302	0.589
PEA	0.361	0.554	0.643	0.432	0.033	0.858
HI	0.385	0.542	1.252	0.276	0.513	0.482
PHI	1.269	0.273	0.011	0.918	3.565	0.073
VI	0.59	0.451	1.723	0.203	0.828	0.373
PVI	0.334	0.569	0.021	0.887	1.571	0.224
HIF	1.057	0.316	0.034	0.856	—	—
PHIF	2.285	0.146	0.088	0.77	—	—
HIH	2.324	0.142	0.438	0.515	—	—
PHIH	0.057	0.813	5.738	0.026	—	—
VIH	0.413	0.527	0.872	0.361	—	—
PVIH	0.342	0.565	1.015	0.325	—	—

* "P" before a variable name refers to post-test.

APPENDIX M:

REPEATED MEASURES MANOVA RESULTS FOR DIVE START VARIABLES

VARIABLE	GROUP F	GROUP Sig of F	TIME F	TIME Sig of F	GROUP * TIME F	GROUP * TIME Sig of F
BT	0.289	0.833	2.913	0.061	0.214	0.885
FT	0.319	0.812	6.278	**0.004**	0.264	0.850
TT	0.234	0.871	2.532	0.088	0.041	0.989
FD	0.172	0.914	0.689	0.570	0.912	0.454
V	1.195	0.338	2.668	0.077	2.973	0.058
TA	0.355	0.786	8.967	**0.001**	3.605	**0.032**
EA	0.300	0.825	0.878	0.470	1.261	0.316
HI	1.669	0.207	16.221	**0.000**	3.685	**0.030**
VI	0.791	0.514	3.786	**0.028**	1.320	0.297
HIF	1.579	0.231	13.254	**0.000**	0.000	1.000
HIH	0.202	0.819	5.402	**0.013**	4.801	**0.020**
VIH	0.105	0.901	7.083	**0.005**	1.452	0.258

APPENDIX N:

DESCRIPTIVE DATA AND UNIVARIATE ANOVA RESULTS FOR DIVE START VARIABLES – SPSS OUTPUT

BLOCK TIME

Descriptive Statistics

	GROUP	Mean	Std. Deviation	N
block time grab	1.00	.9345	5.047E-02	11
	2.00	.9258	7.051E-02	12
	Total	.9300	6.053E-02	23
PBTG	1.00	.9582	.1072	11
	2.00	.9458	5.213E-02	12
	Total	.9517	8.139E-02	23
block time track	1.00	.9555	7.289E-02	11
	2.00	.9679	7.545E-02	12
	Total	.9620	7.281E-02	23
PBTT	1.00	.9455	8.214E-02	11
	2.00	.9308	7.763E-02	12
	Total	.9378	7.833E-02	23
block time swing	1.00	1.1286	9.626E-02	11
	2.00	1.1533	6.830E-02	12
	Total	1.1415	8.187E-02	23
PBTS	1.00	1.0964	8.334E-02	11
	2.00	1.1142	8.597E-02	12
	Total	1.1057	8.328E-02	23

Univariate Tests

Sphericity Assumed

Source	Measure	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
TIME	GRAB	5.464E-03	1	5.464E-03	1.934	.179	1.934	.264
	TRACK	6.361E-03	1	6.361E-03	2.071	.165	2.071	.279
	SWING	1.465E-02	1	1.465E-02	5.719	.026	5.719	.626
TIME * GROUP	GRAB	3.794E-05	1	3.794E-05	.013	.909	.013	.051
	TRACK	2.105E-03	1	2.105E-03	.685	.417	.685	.124
	SWING	1.364E-04	1	1.364E-04	.053	.820	.053	.056
Error(TIME)	GRAB	5.933E-02	21	2.825E-03				
	TRACK	6.451E-02	21	3.072E-03				
	SWING	5.378E-02	21	2.561E-03				

a. Computed using alpha = .05

FLIGHT TIME

Descriptive Statistics

	GROUP	Mean	Std. Deviation	N
flight time grab	1.00	.2527	9.166E-02	11
	2.00	.2425	5.770E-02	12
	Total	.2474	7.424E-02	23
PFTG	1.00	.2745	7.866E-02	11
	2.00	.2717	8.077E-02	12
	Total	.2730	7.795E-02	23
flight time track	1.00	.2727	7.682E-02	11
	2.00	.2508	7.292E-02	12
	Total	.2613	7.394E-02	23
PFTT	1.00	.2891	6.774E-02	11
	2.00	.2825	7.149E-02	12
	Total	.2857	6.821E-02	23
flight time swing	1.00	.2673	7.143E-02	11
	2.00	.2517	6.118E-02	12
	Total	.2591	6.522E-02	23
PFTS	1.00	.2927	7.564E-02	11
	2.00	.2867	6.746E-02	12
	Total	.2896	6.990E-02	23

Univariate Tests

Sphericity Assumed

Source	Measure	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
TIME	GRAB	7.459E-03	1	7.459E-03	12.117	.002	12.117	.913
	TRACK	6.620E-03	1	6.620E-03	6.811	.016	6.811	.702
	SWING	1.049E-02	1	1.049E-02	16.576	.001	16.576	.973
TIME * GROUP	GRAB	1.550E-04	1	1.550E-04	.252	.621	.252	.077
	TRACK	6.720E-04	1	6.720E-04	.691	.415	.691	.125
	SWING	2.615E-04	1	2.615E-04	.413	.527	.413	.094
Error(TIME)	GRAB	1.293E-02	21	6.156E-04				
	TRACK	2.041E-02	21	9.719E-04				
	SWING	1.329E-02	21	6.327E-04				

a. Computed using alpha = .05

TOTAL TIME

Descriptive Statistics

	GROUP	Mean	Std. Deviation	N
time to entry grab	1.00	1.1873	9.264E-02	11
	2.00	1.1683	7.673E-02	12
	Total	1.1774	8.330E-02	23
PTTG	1.00	1.2327	.1304	11
	2.00	1.2175	6.482E-02	12
	Total	1.2248	9.945E-02	23
time to entry track	1.00	1.2282	.1062	11
	2.00	1.2179	8.058E-02	12
	Total	1.2228	9.166E-02	23
PTTT	1.00	1.2345	7.866E-02	11
	2.00	1.2133	.1081	12
	Total	1.2235	9.364E-02	23
time to entry swing	1.00	1.3959	.1015	11
	2.00	1.4050	6.512E-02	12
	Total	1.4007	8.260E-02	23
PTTS	1.00	1.3891	9.093E-02	11
	2.00	1.4008	.1052	12
	Total	1.3952	9.657E-02	23

Univariate Tests

Sphericity Assumed

Source	Measure	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
TIME	GRAB	2.569E-02	1	2.569E-02	7.936	.010	7.936	.766
	TRACK	9.095E-06	1	9.095E-06	.003	.957	.003	.050
	SWING	3.463E-04	1	3.463E-04	.111	.743	.111	.062
TIME * GROUP	GRAB	3.954E-05	1	3.954E-05	.012	.913	.012	.051
	TRACK	3.439E-04	1	3.439E-04	.113	.740	.113	.062
	SWING	2.017E-05	1	2.017E-05	.006	.937	.006	.051
Error(TIME)	GRAB	6.798E-02	21	3.237E-03				
	TRACK	6.376E-02	21	3.036E-03				
	SWING	6.565E-02	21	3.126E-03				

a. Computed using alpha = .05

FLIGHT DISTANCE

Descriptive Statistics

	GROUP	Mean	Std. Deviation	N
flight distance, grab	1.00	264.473	24.2697	11
	2.00	264.542	23.7303	12
	Total	264.509	23.4372	23
PFDG	1.00	265.636	20.5732	11
	2.00	265.167	34.9567	12
	Total	265.391	28.3449	23
flight distance, track	1.00	286.373	18.1327	11
	2.00	280.025	28.5212	12
	Total	283.061	23.8053	23
PFDT	1.00	282.364	22.7124	11
	2.00	284.833	30.8658	12
	Total	283.652	26.6912	23
flight distance, swing	1.00	273.023	18.4749	11
	2.00	270.842	24.3218	12
	Total	271.885	21.2641	23
PFDS	1.00	274.182	22.2792	11
	2.00	277.833	32.5292	12
	Total	276.087	27.5350	23

Univariate Tests

Sphericity Assumed

Source	Measure	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
TIME	GRAB	9.180	1	9.180	.139	.713	.139	.065
	TRACK	1.833	1	1.833	.017	.898	.017	.052
	SWING	190.639	1	190.639	1.834	.190	1.834	.253
TIME * GROUP	GRAB	.833	1	.833	.013	.912	.013	.051
	TRACK	223.100	1	223.100	2.034	.169	2.034	.275
	SWING	97.620	1	97.620	.939	.344	.939	.152
Error(TIME)	GRAB	1390.091	21	66.195				
	TRACK	2303.797	21	109.705				
	SWING	2182.797	21	103.943				

a. Computed using alpha = .05

VELOCITY

Descriptive Statistics

	GROUP	Mean	Std. Deviation	N
resultant velocity grab	1.00	315.5455	29.8304	11
	2.00	313.0375	22.5883	12
	Total	314.2370	25.7145	23
PVG	1.00	307.3273	26.3259	11
	2.00	315.7833	34.1340	12
	Total	311.7391	30.2695	23
resultant velocity track	1.00	345.6500	27.5262	11
	2.00	341.5250	25.0221	12
	Total	343.4978	25.7274	23
PVT	1.00	333.0818	29.6874	11
	2.00	347.9250	25.6033	12
	Total	340.8261	28.0330	23
resultant velocity swing	1.00	312.4636	33.2634	11
	2.00	321.3000	17.6295	12
	Total	317.0739	26.0519	23
PVS	1.00	311.3727	35.5354	11
	2.00	333.8917	35.4069	12
	Total	323.1217	36.5116	23

Univariate Tests

Sphericity Assumed

Source	Measure	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
TIME	GRAB	85.934	1	85.934	1.010	.326	1.010	.160
	TRACK	109.177	1	109.177	.767	.391	.767	.133
	SWING	379.550	1	379.550	2.283	.146	2.283	.303
TIME * GROUP	GRAB	344.949	1	344.949	4.056	.057	4.056	.485
	TRACK	1032.446	1	1032.446	7.257	.014	7.257	.729
	SWING	537.220	1	537.220	3.231	.087	3.231	.404
Error(TIME)	GRAB	1785.867	21	85.041				
	TRACK	2987.508	21	142.262				
	SWING	3491.504	21	166.262				

a. Computed using alpha = .05

TAKE-OFF ANGLE

Descriptive Statistics

	GROUP	Mean	Std. Deviation	N
take-off angle grab	1.00	-5.2455	8.4636	11
	2.00	-8.1000	6.0936	12
	Total	-6.7348	7.2974	23
PTAG	1.00	-5.1091	7.5718	11
	2.00	-7.6000	6.1640	12
	Total	-6.4087	6.8320	23
take-off angle track	1.00	-10.7864	7.3479	11
	2.00	-13.3167	7.4142	12
	Total	-12.1065	7.3278	23
PTAT	1.00	-10.1909	7.6020	11
	2.00	-10.1167	5.6018	12
	Total	-10.1522	6.4776	23
take-off angle swing	1.00	-6.8045	7.2617	11
	2.00	-9.2708	7.1212	12
	Total	-8.0913	7.1352	23
PTAS	1.00	-6.1545	6.9155	11
	2.00	-7.5833	6.9157	12
	Total	-6.9000	6.7959	23

Univariate Tests

Sphericity Assumed

Source	Measure	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
TIME	GRAB	1.162	1	1.162	.790	.384	.790	.136
	TRACK	41.337	1	41.337	22.745	.000	22.745	.995
	SWING	15.679	1	15.679	11.146	.003	11.146	.889
TIME * GROUP	GRAB	.379	1	.379	.258	.617	.258	.077
	TRACK	19.466	1	19.466	10.711	.004	10.711	.877
	SWING	3.089	1	3.089	2.196	.153	2.196	.293
Error(TIME)	GRAB	30.898	21	1.471				
	TRACK	38.166	21	1.817				
	SWING	29.540	21	1.407				

a. Computed using alpha = .05

ENTRY ANGLE

Descriptive Statistics

	GROUP	Mean	Std. Deviation	N
entry angle grab	1.00	40.9727	6.9044	11
	2.00	38.0000	7.9326	12
	Total	39.4217	7.4456	23
PEAG	1.00	39.7591	7.5183	11
	2.00	39.3083	5.9803	12
	Total	39.5239	6.6052	23
entry angle track	1.00	40.6636	6.5995	11
	2.00	38.2500	8.0200	12
	Total	39.4043	7.3128	23
PEAT	1.00	40.7227	8.0549	11
	2.00	39.7917	6.3355	12
	Total	40.2370	7.0559	23
entry angle swing	1.00	38.5591	6.5077	11
	2.00	35.9333	7.1061	12
	Total	37.1891	6.8042	23
PEAS	1.00	39.1273	7.4580	11
	2.00	37.2375	6.8865	12
	Total	38.1413	7.0659	23

Univariate Tests

Sphericity Assumed

Source	Measure	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power [a]
TIME	ENTANGG	2.6E-02	1	2.6E-02	.004	.948	.004	.050
	ENTANGT	7.353	1	7.353	.696	.413	.696	.125
	ENTANGS	10.060	1	10.060	.745	.398	.745	.131
TIME * GROUP	ENTANGG	18.251	1	18.251	3.125	.092	3.125	.393
	ENTANGT	6.307	1	6.307	.597	.448	.597	.114
	ENTANGS	1.554	1	1.554	.115	.738	.115	.062
Error(TIME)	ENTANGG	122.647	21	5.840				
	ENTANGT	221.707	21	10.557				
	ENTANGS	283.559	21	13.503				

a. Computed using alpha = .05

HORIZONTAL IMPULSE

Descriptive Statistics

	GROUP	Mean	Std. Deviation	N
hor impulse, grab	1.00	176.732	14.0155	11
	2.00	184.533	17.0160	12
	Total	180.802	15.8095	23
PHIG	1.00	163.836	10.1171	11
	2.00	175.933	16.0443	12
	Total	170.148	14.6086	23
hor impulse, track	1.00	201.968	26.6806	11
	2.00	197.646	35.2016	12
	Total	199.713	30.7899	23
PHIT	1.00	198.236	33.6419	11
	2.00	220.392	39.0016	12
	Total	209.796	37.4574	23
hor impulse, swing	1.00	187.618	15.8754	11
	2.00	205.554	22.8009	12
	Total	196.976	21.4108	23
PHIS	1.00	180.891	13.7858	11
	2.00	196.350	21.5949	12
	Total	188.957	19.5422	23

Univariate Tests

Sphericity Assumed

Source	Measure	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power [a]
TIME	GRAB	1325.896	1	1325.896	29.028	.000	29.028	.999
	TRACK	1037.442	1	1037.442	2.958	.100	2.958	.375
	SWING	728.327	1	728.327	6.898	.016	6.898	.707
TIME * GROUP	GRAB	52.946	1	52.946	1.159	.294	1.159	.177
	TRACK	2011.755	1	2011.755	5.736	.026	5.736	.627
	SWING	17.605	1	17.605	.167	.687	.167	.068
Error(TIME)	GRAB	959.201	21	45.676				
	TRACK	7365.687	21	350.747				
	SWING	2217.210	21	105.581				

a. Computed using alpha = .05

VERTICAL IMPULSE

Descriptive Statistics

	GROUP	Mean	Std. Deviation	N
VIG	1.00	59.1636	31.2955	11
	2.00	58.4708	35.9788	12
	Total	58.8022	33.0537	23
PVIG	1.00	62.4273	32.3779	11
	2.00	66.1000	23.8208	12
	Total	64.3435	27.6359	23
VIT	1.00	74.6636	22.3719	11
	2.00	83.3625	37.6459	12
	Total	79.2022	30.9168	23
PVIT	1.00	68.3182	36.1254	11
	2.00	92.0083	36.5451	12
	Total	80.6783	37.5150	23
VIS	1.00	100.3409	17.1279	11
	2.00	105.6500	25.0316	12
	Total	103.1109	21.3071	23
PVIS	1.00	110.5000	26.7880	11
	2.00	127.4750	35.6007	12
	Total	119.3565	32.1723	23

Univariate Tests

Sphericity Assumed

Source	Measure	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
TIME	GRAB	340.483	1	340.483	1.141	.298	1.141	.175
	TRACK	15.185	1	15.185	.073	.790	.073	.058
	SWING	2935.514	1	2935.514	12.442	.002	12.442	.920
TIME * GROUP	GRAB	54.688	1	54.688	.183	.673	.183	.069
	TRACK	644.902	1	644.902	3.089	.093	3.089	.389
	SWING	390.529	1	390.529	1.655	.212	1.655	.233
Error(TIME)	GRAB	6267.374	21	298.446				
	TRACK	4384.050	21	208.764				
	SWING	4954.651	21	235.936				

a. Computed using alpha = .05

HORIZONTAL IMPULSE - FEET

Descriptive Statistics

	GROUP	Mean	Std. Deviation	N
HIFG	1.00	168.1273	16.1619	11
	2.00	180.2083	20.2512	12
	Total	174.4304	19.0226	23
PHIFG	1.00	157.9182	11.6576	11
	2.00	170.0000	18.0762	12
	Total	164.2217	16.2242	23
HIFT	1.00	126.7045	22.1683	11
	2.00	132.0542	24.5557	12
	Total	129.4957	23.0724	23
PHIFT	1.00	121.2636	23.3238	11
	2.00	126.4417	22.6897	12
	Total	123.9652	22.6203	23

Univariate Tests

Sphericity Assumed

Source	Measure	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
TIME	GRAB	1196.239	1	1196.239	27.762	.000	27.762	.999
	TRACK	350.597	1	350.597	1.532	.229	1.532	.219
TIME * GROUP	GRAB	1.647E-06	1	1.647E-06	.000	1.000	.000	.050
	TRACK	8.449E-02	1	8.449E-02	.000	.985	.000	.050
Error(TIME)	GRAB	904.877	21	43.089				
	TRACK	4805.170	21	228.818				

a. Computed using alpha = .05

HORIZONTAL IMPULSE - HANDS

Descriptive Statistics

	GROUP	Mean	Std. Deviation	N
HIHG	1.00	8.6045	7.3308	11
	2.00	4.3250	13.3197	12
	Total	6.3717	10.8588	23
PHIHG	1.00	5.9182	7.4818	11
	2.00	5.9583	7.3058	12
	Total	5.9391	7.2203	23
HIHT	1.00	75.2636	20.5533	11
	2.00	65.5917	32.6611	12
	Total	70.2174	27.3824	23
PHIHT	1.00	77.0091	19.9421	11
	2.00	93.9500	41.1618	12
	Total	85.8478	33.2082	23

Univariate Tests

Sphericity Assumed

Source	Measure	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
TIME	GRAB	3.182	1	3.182	.106	.748	.106	.061
	TRACK	2600.509	1	2600.509	11.098	.003	11.098	.888
TIME * GROUP	GRAB	53.545	1	53.545	1.783	.196	1.783	.247
	TRACK	2032.356	1	2032.356	8.673	.008	8.673	.802
Error(TIME)	GRAB	630.686	21	30.033				
	TRACK	4920.713	21	234.320				

a. Computed using alpha = .05

VERTICAL IMPULSE - HANDS

Descriptive Statistics

	GROUP	Mean	Std. Deviation	N
VIHG	1.00	166.0864	72.7556	11
	2.00	145.9708	68.3044	12
	Total	155.5913	69.6016	23
PVIHG	1.00	169.9091	77.7852	11
	2.00	178.1917	65.9121	12
	Total	174.2304	70.2876	23
VIHT	1.00	195.4045	62.0262	11
	2.00	187.8375	86.9300	12
	Total	191.4565	74.4453	23
PVIHT	1.00	225.5182	90.0703	11
	2.00	240.8417	75.1298	12
	Total	233.5130	81.0621	23

Univariate Tests

Sphericity Assumed

Source	Measure	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
TIME	GRAB	3727.962	1	3727.962	3.780	.065	3.780	.458
	TRACK	19824.590	1	19824.590	12.064	.002	12.064	.912
TIME * GROUP	GRAB	2314.168	1	2314.168	2.347	.140	2.347	.310
	TRACK	1503.584	1	1503.584	.915	.350	.915	.150
Error(TIME)	GRAB	20710.207	21	986.200				
	TRACK	34509.996	21	1643.333				

a. Computed using alpha = .05

APPENDIX O:

PEARSON'S BIVARIATE CORRELATION MATRIX – DRY-LAND TESTS AND FLIGHT DISTANCE

	PVJ	PCMJ	PLEGPOWE	PLEGSTRG	PSHOT1	PSHOT2
PVJ	1.0000 (23) P= .	.7132 (23) P= .000	.5138 (23) P= .012	.1637 (23) P= .456	.6144 (23) P= .002	.4312 (23) P= .040
PCMJ	.7132 (23) P= .000	1.0000 (23) P= .	.7141 (23) P= .000	.4505 (23) P= .031	.7118 (23) P= .000	.4040 (23) P= .056
PLEGPOWE	.5138 (23) P= .012	.7141 (23) P= .000	1.0000 (23) P= .	.7692 (23) P= .000	.6074 (23) P= .002	.3507 (23) P= .101
PLEGSTRG	.1637 (23) P= .456	.4505 (23) P= .031	.7692 (23) P= .000	1.0000 (23) P= .	.1858 (23) P= .396	.1085 (23) P= .622
PSHOT1	.6144 (23) P= .002	.7118 (23) P= .000	.6074 (23) P= .002	.1858 (23) P= .396	1.0000 (23) P= .	.7030 (23) P= .000
PSHOT2	.4312 (23) P= .040	.4040 (23) P= .056	.3507 (23) P= .101	.1085 (23) P= .622	.7030 (23) P= .000	1.0000 (23) P= .
PFDG	.7359 (23) P= .000	.5975 (23) P= .003	.3095 (23) P= .151	.1322 (23) P= .548	.4274 (23) P= .042	.4005 (23) P= .058
PFDS	.8352 (23) P= .000	.6499 (23) P= .001	.3285 (23) P= .126	.0954 (23) P= .665	.4771 (23) P= .021	.4465 (23) P= .033
PFDT	.6896 (23) P= .000	.6270 (23) P= .001	.3362 (23) P= .117	.1903 (23) P= .384	.4393 (23) P= .036	.5645 (23) P= .005