Optimization of the competitive swimming track start based on lower limb asymmetry

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Abstract

The swimming track start is a complex motor skill that utilizes asymmetric lower limb action. The purpose of this study was to explore whether it could be optimized by applying the commonly accepted view that there are asymmetries in the function and behaviors of the lower limbs. Initially, the study aimed to examine the relationship between various measures of lower limb asymmetry and the swimmers' preferences for forward foot placement in the swimming track start. Participants underwent a 7 week training period whereby both the left foot forward (LFF) and the right foot forward (RFF) track starts were practiced. The philosophy behind this training protocol was to ensure that participants received equal practice with the preferred and non-preferred stance so that a dominant stance, if it existed, could emerge. Consequently, the relationships between the dominant track start stance and the lower limb asymmetry measures could be determined more accurately. Participants were male (N=11) and female (N=11) swimmers, aged 12-16 years, from the UWA-Uniswim National Age Squad. Kinetic and kinematic data were collected for the track start prior to and following the 7 week training intervention. The intervention was finished when a participant had completed approximately 14 dive sessions where both the LFF and RFF track starts were practiced. The performance criterion measure was time to 5 m. Despite significant differences in vertical force and velocity contributions following the intervention, time to 5 m did not improve for either the LFF or the RFF track start. Four different measures of lower limb asymmetry were collected, including footedness, the preferred track start stance, and the dominant take-off limb for the unilateral and bilateral counter-movement jump (CMJ). Sixteen of 22 participants displayed changes in their dominant track start stance. Eleven participants showed biases for one stance (6 for the LFF & 5 for the RFF), and 11 participants remained or became more symmetrical. Results indicated that the preferred track start stance was the only measure of asymmetry that was significantly related to track start performance ($\chi^2_{[2]}$=

6.71, p=.04 for pre-intervention & $\chi^2_{[2]}$=7.77, p=.02 for post-intervention). All other measures of lower limb asymmetry were shown to be unrelated to track start preference and performance. It was suggested that the 7 week training intervention did not provide a sufficient amount of time to see conclusive effects on 5 m time or to make conclusive comparisons between the dominant track start stance and measures of asymmetry. Since the preferred track start corresponded with better performance less than 50% of the time, it was suggested that swimmers and coaches experiment with different dive techniques to find the start which is most effective for them and spend more time on them during training.

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Chapter 1

1 THE PROBLEM

1.1 Introduction

In the sport of swimming, the outcomes of many races are determined by a margin of as little as .01 s. For example, in the 2007 FINA World Swimming Championships, the top three finishers of the men's 100-meter freestyle were separated by only .04 s, and the remainder of the top eight finished within .38 s of the winner (Federation Internationale de Natation (FINA), 2007). Hence, every .01 s lost or gained from the start, turn, and stroke efficiency influences one's opportunity for a medal. While the dive start comprises a small part of the race, the advantage gained from a good start can be the difference between winning and losing (Ayalon, Van Gheluwe, & Kanitz, 1975; Hobbie, 1980).

The track and grab starts are the most common starting techniques used by swimmers (Benjanuvatra, Lyttle, Blanksby, & Larkin, 2004; Counsilman, Counsilman, Nomura, & Endo, 1988; Issurin & Verbitsky, 2003; Miller, Allen, & Pein, 2003). The track start is characterized by asymmetric foot placement, with one foot placed at the front of the starting block and the other farther back. The hands grab onto the forward edge of the block, and the body weight is centered over the front foot. This technique is different from the grab start where both feet and hands are placed on the front edge of the block. In addition to the grab and track starts, a modified version of the track start has recently emerged. It is referred to as the slingshot start because the swimmer leans back in the ready position to generate "pre-tension" in the shoulder and lower limb muscles prior to the starting signal.

Given the asymmetric nature of the track start, a question is raised in regards to optimal foot placement on the block and the interaction of limb asymmetry on force production in order to enable performance of a consistently superior start. Research tends to support the idea that the front foot contributes more than the rear foot in the production of horizontal propulsion (Ayalon et al., 1975; Breed & McElroy, 2000; Lyttle & Benjanuvatra, 2006; Verrier, 1985). This appears to be a logical assumption because the front foot remains on the block longer than the rear foot. Since the lower limbs contribute unequally to horizontal propulsion, one factor that may affect dive performance is lower limb asymmetry. Currently, the relationship between lower limb asymmetry and foot placement during the track start has not been explored. Therefore, it was deemed valuable to examine measures of lower limb preference and dominance and their relationship with differing foot placements for the track start using a force plate instrumented starting block.

1.2 Statement of the Problem

The purpose of this study was to examine the relationship between lower limb asymmetry and placement of the front and rear feet in the swimming track start. It is understood that most swimmers would have a preference for either the left foot forward (LFF) or the right foot forward (RFF) track start technique. As such, this study aimed to determine whether one stance would enable superior track start performances in comparison to the other and whether the preferred technique would lead to better 5 m performances as compared to the non-preferred technique. Similarly, this study aimed to reveal whether a period of training both the LFF and the RFF track starts would result in the emergence of a true superior (or dominant) stance as determined by 5 m time. An additional purpose was to determine whether the dominant track start stance and the preferred track start stance were related to other measures of lower limb asymmetry.

More specifically, the following questions were investigated:

- Can preferences for the track start stance and track start performances be predicted by any of the following variables:
  - Asymmetries in the net vertical take-off impulse of the unilateral counter-movement jump (CMJ)
  - Asymmetries in the net vertical take-off impulse of the bilateral CMJ
  - The preferred limb as assessed by the Waterloo Footedness Questionnaire – Revised (Elias, Bryden, & Bulman-Fleming, 1998)
- Does the preferred stance enable faster track start performance than using the alternate foot position?
- Does a 7 week period of practice, using both the left foot forward and the right foot forward stances, change the athletes' track start performances to reflect any of the following variables:
  - Asymmetries in the net vertical take-off impulse of the unilateral CMJ
  - Asymmetries in the net vertical take-off impulse of the bilateral CMJ
  - The preferred limb as assessed by the Waterloo FQ – Revised (Elias et al., 1998)
- Following a 7 week training period, does the preferred stance enable faster track start performance than using the alternate foot position?

1.3 Significance of Study

With several different starting techniques available, it is natural that swimmers will develop preferences for one technique over another. However, technical selection is usually based on factors such as comfort, previous experiences, or coach preferences rather than scientific evidence (Benjanuvatra, et al., 2004). Thus, scientifically based insights into the components of starting techniques have the potential to greatly benefit swimmers.

1.4 Hypotheses

It is hypothesized that each of the measures of lower limb asymmetry will relate to track start preference and performance. It is also predicted that the preferred track start will enable a faster 5 m time than the non-preferred start. Finally, it is hypothesized that track start performance will improve following a 7 week training intervention.

1.5 Delimitations and Limitations

1.5.1 Delimitations

- Participants were limited to age group swimmers from the UWA-Uniswim program who had achieved a qualifying standard at the Western Australian State Championships competition. This was to ensure that the swimmers were competent, but also that they would have room for improvement, so a training effect could be induced.

1.5.2 Limitations

- Participants may have been active in various other sports and activities throughout the intervention, and this may have influenced their performance through the testing.

1.6 Definition of Terms

- Track start: swimming dive start technique which is characterized by asymmetric foot placement with body weight centered over the front foot.
- Lower limb asymmetry: difference in amount of use or level of performance for motor tasks between the two lower limbs.
- Foot preference: the general propensity to use one lower limb over another for a given task (Provins, 1997).
- Foot dominance: superior performance or greater contribution of one lower limb over the other in a specific motor task (Provins, 1997).

- Counter-movement jump (CMJ): unilateral or bilateral vertical jump where the jumper starts in an upright position and makes an initial downward movement by flexing at the knees before extending the knees to jump vertically off the ground.

1.7 List of Abbreviations

- Left foot forward: LFF
- Right foot forward: RFF
- Counter-movement jump: CMJ
- Ground reaction force: GRF
- Center of mass: COM
- Reaction time: RT
- Movement time: MT
- Total block time: BT
- Peak horizontal force: F_{hor}
- Peak vertical force: F_{vert}
- Net horizontal impulse: I_{hor}
- Net vertical impulse: I_{vert}
- Horizontal take-off velocity: V_{hor}
- Vertical take-off velocity: V_{vert}
- Net take-off velocity: V_{net}
- Take-off angle: TOA
- Light-emitting diodes: LEDs
- Waterloo Footedness Questionnaire – Revised: WFQ-R
- Analysis of Variance: ANOVA

Chapter 2

2 REVIEW OF RELATED LITERATURE

2.1 The Swimming Track Start

2.1.1 Description of the track start

The track start is a popular alternative to other techniques as it offers a number of advantages (Rutemiller, 1995). When compared to the grab start, where both feet are placed at the front of the block, the staggered foot placement, or stance, widens the base of support. Subjectively, the track start achieves greater stability (Fitzgerald, 1973; Rutemiller, 1995). As a result, swimmers can get into and maintain their starting positions more easily, and the risk of false starting is reduced (Rutemiller, 1995). The track start is performed by placing one foot at the front of the starting block with the toes curled over the edge and the other foot placed towards the back of the block. The hands grip the front edge of the block for stability, and body weight is centered over the front foot.

A popular variant to the track start is the slingshot track start (Rutemiller, 1995). The slingshot start utilizes the same asymmetric stance as the track start, but body weight is shifted towards the rear leg instead of over the front leg.

2.1.2 Track start effectiveness

Previous studies of the various starting techniques have yielded inconclusive results (Ayalon et al., 1975; Blanksby, Nicholson, & Elliott, 2002; Breed & McElroy, 2000; Counsilman et al., 1988; Hobbie, 1980; Issurin & Verbitsky, 2003; Kruger, Wick, Hohmann, El-Bahrawi, & Koth, 2003; Miller, et al., 2003; Pearson, McElroy, Blitvich, Subic, & Blanksby, 1998).

Typically, the measure of effectiveness for a dive is the time taken to reach a certain distance, usually between 5 and 15 m from the starting block, with 15 m being the maximum limit of the underwater swimming phase based on FINA regulations. Using this criterion, no significant differences were found between the performances of the track and grab starts at 6 m (Benjanuvatra et al., 2004) or 10m (Blanksby et al., 2002; Counsilman et al., 1988). However, in an investigation of starting techniques at the 2000 Sydney Olympic Games, Issurin and Verbitsky (2003) found that swimmers using the track start tended to have faster 15 m times, but the difference reached statistical significance in only five out of thirteen women's events. In contrast, Ayalon et al. (1975) and Kruger et al. (2003) found that the grab start was faster than the track start to 5 m and 7.5 m, respectively. However, while the bunch start in the Ayalon et al. study (1975) was essentially equivalent to the modern track start, the exact foot placements and body positions were unclear. In addition, the track start was a new technique, with which the majority of their participants were not familiar. As a result, the superior performance of the grab start to 5 m may have reflected the lack of experience and practice with the track start. It also should be noted that in the study by Kruger et al. (2003), the participants were elite swimmers, and the majority had a preference for and greater practice time with the grab start. Thus, these swimmers may have performed better because they were more familiar with this technique.

Comparisons have revealed that the track start tends to enable swimmers to react and move off the blocks more quickly, but the grab start tends to produce greater take-off velocities and force when leaving the block (Ayalon et al., 1975; Benjanuvatra et al., 2004; Issurin & Verbitsky, 2003; Kruger et al., 2003; Miller et al., 2003). While force measurements were not recorded in their studies, Ayalon et al. (1975) and Issurin and Verbitsky (2003) found that the track starters reacted quicker and spent less time on the blocks as compared with grab starts. Similar findings were reported by Benjanuvatra et al. (2004) when comparing the track and grab starts of 16 national level swimmers. They found that when the swimmers performed the grab start, they stayed on the starting block for an average of .06 s longer but were able to generate .55 ms^{-1} greater take-off velocity when compared with the track start. They also concluded that the grab start enabled higher horizontal impulse, higher average horizontal force, and higher peak vertical force. Only Breed and McElroy (2000) have reported significantly higher horizontal impulse in the track start when compared with the grab start. However, they attributed the greater horizontal impulse in the track start to extra work done by the arms. It is important to note that the participants in this study were university P.E. students who had very little swimming experience and had to be taught the dive techniques prior to the experiment. Also, the study utilized the rear weighted (slingshot) track start, which uses the arms to pull back on the block to lean the body weight back towards the rear foot.

It seems there could be a trade-off between being quick off the block and generating greater force. Either one can move off the blocks quicker in order to start swimming sooner, or one can take a little more time but leave the block with greater force in order to enter the water at a greater velocity. Indeed, Benjanuvatra et al. (2004) noted that despite higher force and velocity for the grab start, or conversely, faster block time for the track start, both starts yielded similar times to 6 m. Given the differing physical characteristics of swimmers, this trade-off between block time and force production can potentially be used to optimize start performances.

Due to the asymmetric nature of the track start, differences in force contributions between limbs are expected. The majority of research supports the idea that the front foot contributes more than the rear foot to horizontal propulsion (Ayalon et al., 1975; Breed & McElroy, 2000; Lyttle & Benjanuvatra, 2006; Verrier, 1985). The front foot stays on the block for a longer period of time, and it provides the final thrust to project the body forward (Lyttle & Benjanuvatra, 2006). According to claims by Breed and McElroy (2000), the rear leg actually contributes little to the production of horizontal impulse. Others have reported similar conclusions, despite lacking empirical evidence (Ayalon et al., 1975; Lyttle & Benjanuvatra, 2006; Verrier, 1985).

Only one study to date has actually separated out the force contributions of the individual lower limbs in the track start, and the results were mixed (Benjanuvatra et al., 2004). In this study, Benjanuvatra et al. (2004) surveyed the bilateral ground reaction force (GRF) profiles of the track start in 16 national level swimmers and reported variations across all swimmers. While the rear foot was on the block for less time than the front foot, the number of swimmers who generated greater impulse with the rear foot was almost equal to the number of swimmers who generated greater impulse with the front foot. The author could not offer a clear explanation for these results but suggested that the varying force profiles could be attributed to the variability in skill proficiencies. The study assumed that the participants were proficient with this starting technique due to their status as elite swimmers and the fact that they all preferred the track start. However, an earlier study that examined the performances of the preferred and the non-preferred dive start techniques showed that this assumption may not be appropriate (Blanksby et al., 2002). They revealed that all swimmers, including elite, improved significantly in both the preferred and non-preferred techniques following 14 dive start training sessions. The significant improvements in just 14 sessions in elite swimmers highlighted the fact that starts are often neglected in training, and all swimmers could benefit from more time being allocated to dive starts.

Considering these findings, it appears that the front lower limb contributes the most to force production and propulsion in the track start. Given this disparity between limb actions, one factor that could influence the overall performance of a track start is lower limb asymmetry. Currently, associations between the limb that a swimmer chooses to place at the front of the block and measurements of lower limb preference and lower limb dominance have not been explored.

2.2 Lower Limb Asymmetries

2.2.1 Asymmetry: dominance vs. preference

People demonstrate asymmetry in the way the upper and lower limbs are used in any day-to-day tasks. In the upper limb, a commonly accepted view is that the preferred hand is closely linked to better performance (Annett, 1970). Because of this link, the terms dominance and preference have been used interchangeably in the literature. For example, Peters (1988) used the notion of preference for mobilizing or supportive tasks to describe foot dominance. That is the preferred foot performs mobilizing tasks such as manipulating objects, and therefore, is the dominant foot. However, Porac and Coren (1981) argued that lateral preference suggests an element of choice, and does not necessarily link to skill or strength proficiencies. While the agreement between proficiency and preference may be high in skilled tasks, Provins (1997) suggested that this agreement could be due to the preferred limb having more practice. In a less common, or less skilled, motor task, performance differences between limbs are not as obvious. For example, Corey, Hurley, and Foundas (2001) found that proficiencies for handwriting correlated significantly with hand preference, whereas performance asymmetries in finger tapping and pegboard tasks did not always identify right- and left-handed individuals. Grip strength has also been demonstrated to be a poor predictor of hand preference (Rigal, 1992).

The evidence tends to support the notion that proficiency and preference are not the same. Therefore, they should be treated differently when motoric asymmetries are discussed. For this reason, the term dominance will be used to indicate superior performance or greater contribution in a specific motor task, and preference will refer to the general propensity to use one limb over another. Since the preferred limb is not always the limb that exhibits better performance, it may be beneficial to include preference measures and dominance measures to see if they correlate to the track start stance preference and performance of the track start.

2.2.2 Measurement of foot preference

The most common assessment method of lateral preference is via the administration of a questionnaire (Chapman, Chapman, & Allen, 1987; Grouios, 2005; Rigal, 1992). In general, questionnaires will ask participants which hand or foot they prefer to use when performing certain tasks. In a footedness questionnaire, the battery of tasks may include balancing and stabilization tasks, as well as mobilizing and manipulative tasks to reflect different functional characteristics of the lower limbs. Participants answer each question by selecting from the following typical response options: “left always”, “left usually”, “left or right equally”, “right usually”, and “right always” (Rigal, 1992). Thus, the strength of preference for one side can be assessed wherein a person may not necessarily have a complete preference for their left or right side, but they may fall anywhere along that continuum. While self-report questionnaires allow quick and easy assessment of limb preference, there is the potential problem of subjectivity of the response. Participants often have to recall or imagine what they would do in each situation. Nonetheless, questionnaire assessments have been found to be valid and reliable (Chapman et al., 1987). One recognized measurement of this kind is the Waterloo Footedness Questionnaire – Revised (Elias et al., 1998). This questionnaire contains 10 items assessing foot preference for 2 types of tasks as well as for overall preference. Half of the questions on this inventory assess foot preference for manipulative tasks (such as which limb is used to kick a ball). The other half of the questions assesses preference for supportive tasks (such as which foot would be used to balance on a railway track). The measurement of limb preference may be of importance when studying lower limb actions during the track start. Those who display strong preferences for a particular limb may perform better on the track start with that limb placed at the front of the starting block.

2.2.3 Foot dominance and the track start

While a person might generally prefer to use one limb over another, this preference may or may not be related to superior performance in given tasks. For example, in a number of handedness studies, greater performance on finger tapping, pegboard, and grip strength tasks did not always correspond with a participant's preferred hand for that particular task (Corey et al., 2001; Rigal, 1992). Similar findings have been reported in regards to lower limb dominance as well. In a study on motor asymmetries and clumsiness, Armitage and Larkin (1993) reported that among a group of normal 8-9 year olds, 30% performed better in a hopping task when hopping on their non-preferred foot, 15% performed better on a balancing task, and 20% performed better on a foot tapping task. Similarly, Chapman et al. (1987) found that the tasks of balancing on one foot and using one foot to step up onto a stool both had poor correlations with foot preference. These results suggest that limb dominance is task dependent, and dominance is not always related to preference.

Sadeghi, Allard, Prince, and Labelle (2000) suggested that a single definition of foot dominance may not be sufficient, and it should be labeled in the context of the task that is undertaken, whether for stability, mobility, or bilaterality. They also mentioned that task complexity should be considered when defining foot dominance. These suggestions were supported by findings of Hart and Gabbard (1997) in their study of footedness and stabilization. They found that in a bilateral task, such as kicking a ball, the act of stabilizing the body was relatively simple in comparison to the complex demands of kicking the ball. In this case, there was a preferred limb for support and a preferred limb for mobilization. However, in the context of a simpler unilateral balancing task, approximately 50% of the participants switched to using their preferred mobilizing limb for stabilization. They concluded that foot preference was not universal but that it was at least partially dependent on the nature and complexity of the task. Taking these arguments into account, multiple measures of foot dominance may provide a more complete picture than any one measure.

If foot dominance is related to the nature of the task, whether the dominant limb for one task can be predicted by the dominant limb of another task with similar action elements remains inconclusive. Both vertical jumps and swim starts have been found to be complex, explosive skills that utilize leg power for propulsion (Benjanuvatra, Edmunds, & Blanksby, 2007; Breed & Young, 2003; Pearson et al., 1998). Robertson and Stewart (1997) found that the swimming start recruits leg muscles nearly simultaneously, which is similar to the muscle recruitment of a vertical jump. Certainly, studies have reported that start efficiency, specifically flight time and glide time, is correlated with jumping ability (Breed & Young, 2003; Zatsiorski, Bulgakova, & Chaplinsky, 1979). For this reason, a unilateral vertical jump test may be a close representation of leg dominance as it relates to the track start. In fact, Maulder and Cronin (2005) reported that differences between limbs on a unilateral jumping task can be used to determine leg asymmetry.

In addition to a unilateral vertical jump task, it may be constructive to look at limb interactions on a bilateral vertical jump task since both feet work together to propel the body for the track start. While it seems that both legs should contribute equally during a bilateral vertical jump, Benjanuvatra, Blanksby, and Larkin (2003) found ranging asymmetries among participants who performed trials of two-legged counter-movement jumps. Of their 44 participants, 6 showed a stronger left bias, 9 showed a stronger right bias, and 29 fluctuated around symmetry. These findings may be important in the context of a track start where the lower limbs contribute separately and unequally to the production of propulsion. It may be that the foot that contributes more to the propulsion in the unilateral or the bilateral vertical jumps will be related to the dominant track start stance.

2.3 Summary

In summary, the track start may exhibit advantages over other techniques, specifically concerning the ability to move off the blocks more quickly. While faster block times seem to be a trade-off with higher force production, propulsion should still be optimized. Given the asymmetric nature of the track start, lower limb preference and dominance could play a role in overall track start performance. Research tends to support the idea that the forward placed foot contributes more than the rear foot to horizontal propulsion, so it may be more effective to place the dominant foot at the front of the block. This study aims to examine the interaction of lower limb asymmetry and foot placement on the performance capabilities of the track start.

Chapter 3

3 METHODS AND PROCEDURES

3.1 Participants

Eleven female and 11 male age-group swimmers (12-16 years old) from the UWA-Uniswim program at the University of Western Australia participated in the study. All participants were required to have at least reached State Championship qualifying standards. Following Human Rights approval, information regarding the test protocol and the risks and benefits of the study was distributed to the participants. Parental and swimmer consent was obtained prior to testing.

3.2 Training Intervention

All participants underwent a 7 week training intervention. Over this 7 week period, start practice was conducted in the last 15 minutes of regular swimming sessions. This timing was chosen because it was common practice for the swimmers in this club to practice dives at the end of training sessions. As a result, normal training could be kept as normal as possible, and the disruption caused by the research protocol could be kept to a minimum. Swimmers were required to attend a minimum of 12 start training sessions over the 7 week period. The maximum number of sessions attended was 16. In each training session, the swimmers performed 16 repeats of the track start (8 using the left foot forward stance and 8 using the right foot forward stance). These dives were performed in a block order with all 8 of one stance completed before moving on to the other stance. An attempt was made to keep the order randomized for each participant from session to session; however, not all participants were in attendance at all offered training sessions. Swimmers were given coaching feedback on their performances at every training session. Specifically, swimmers were instructed to lean forward and center their weight over their front foot. They were also instructed to project themselves at a low angle off the blocks. The swimmers did not receive any other dive start training throughout the period of the intervention.

3.3 Testing Procedures

All participants followed the same protocols and attended three sessions at the School of Sport Science, Exercise and Health aquatic laboratory for familiarization, pre-intervention assessment, and post-intervention assessment. The protocols on the pre-intervention test and the post-intervention test were run in a similar manner, and the results from the pre-intervention test acted as the control values for the participants.

3.3.1 Performance of track start trials

At the beginning of each testing session, each participant was asked to complete a brief questionnaire about their swimming and track start experience. This questionnaire also determined whether the swimmer preferred the LFF or the RFF stance when performing the track start. Their height and mass were also recorded. Prior to the track start trials, participants were given a standardized warm-up of 600 m of swimming followed by 4 practice track starts. Participants were instructed to perform the track starts with their body weight centered over their front foot and also to glide to at least 8m upon entering the water in order to make certain that the participant passed completely through the 5 m mark before standing up. The glide to 8 m also ensured that little to no extraneous body motion (i.e. kicking) contributed to 5 m time so that any differences between dives would be more likely attributed to differences due to actions on the block. The 5 m distance was chosen as the criterion variable because it was a long enough distance for the dive to be completed with the participant's motion stabilized in a glide.

Following the warm-up, each participant performed 5 maximal effort track starts with the left foot forward and 5 with the right foot forward. These trials were administered in a block order where all 5 of one condition were performed before completing the other condition. Trial order was randomized between participants to minimize interaction effects, and at least 2 minutes were allowed in between trials to avoid the onset of muscle fatigue.

The track starts were performed on a custom-built force plate instrumented starting block. The dimensions of the block were in accordance with FINA regulations. Ground reaction force data were collected at 500 Hz using a custom-programmed data collection software and were low-pass filtered at 16 Hz before processing. The following variables were then derived to the precision of .002: reaction time (RT), movement time (MT), total block time (BT), peak horizontal force (F_{hor}), peak vertical force (F_{vert}), net horizontal impulse (I_{hor}), net vertical impulse (I_{vert}), horizontal take-off velocity (V_{hor}), vertical take-off velocity (V_{vert}), net take-off velocity (V_{net}), and take-off angle (TOA). Two Sony digital cameras (50 Hz) were used to determine 5 m time to the nearest .02 s. One camera was positioned on the deck perpendicular to the starting block and was used during data processing to ensure that there were no false starts or abnormalities in the starting techniques. The other camera was positioned in an underwater viewing area 5 m from the starting edge of the pool and perpendicular to the swimmers' line of motion. Two light-emitting diodes (LEDs) were placed in the field of motion of both cameras, and they were connected to an auditory starting signal. When the starter triggered the signal, both LEDs were illuminated. The 5 m time was determined from the length of time between the initial illumination of the LED to the point when the bottom edge of the swimmer's bathing suit (near the greater trochanter) crossed the 5 m line. Because the swimmers were gliding and maintaining a relatively fixed posture between trials, the bottom edge of the bathing suit was considered a good choice of a fixed point on the body which could accurately reflect the translational motion of the whole body. All of the participants' bathing suits were tight enough that they did not shift upon entering the water, and the contrast of color ensured that 5m time could be determined even through the presence of air bubbles.

3.3.2 Unilateral and bilateral counter-movement jump (CMJ) trials

For both the pre-intervention and the post-intervention tests, the CMJ trials were performed directly following the completion of the track start trials. There was a rest period of at least 5 minutes following the track starts in order to allow time for set up and also to allow some time for recovery. Participants then performed 5 maximal effort vertical CMJs with the left leg, 5 with the right leg, and 5 with both legs concurrently. These trials were administered in block order with all 5 of one condition being completed before progressing to the next condition. Trial order was randomized between participants to minimize interaction effects, and at least 2 minutes were allowed between trials to avoid the onset of muscle fatigue. All jumps were performed with bare feet to avoid effects found between different types of shoes. Participants were instructed to perform all trials with hands on their hips to avoid differing momentum effects due to arm swinging motions. In addition, participants were asked to remain stable on the force plate for at least 2 seconds before completing each jump to ensure a static period on the force-time curve. This also helped ensure that accurate detection of initial movement could be more easily determined. All unilateral CMJs were performed on a Kistler force plate. In order to determine the individual GRF contributions of each leg for the bilateral CMJs, two force plates were employed with one foot placed on each plate.

Ground reaction force data were collected at 500 Hz with an AMTI force plate and a Kistler force plate. The following variables were calculated for each CMJ using equations based on the data output: peak vertical force, net vertical take-off impulse, and jump height. Video footage was also collected with a Sony digital camera (50 Hz) set up in the sagittal plane perpendicular to the participant. This footage was used to ensure that only valid trials were used in the data analysis.

3.3.3 Determination of the dominant stance for the track start

The dominant track start stance was determined by comparing the top 3 trials of the LFF and the RFF stances based on 5 m time. This was done for the pre-intervention test and also for the post-intervention test. The best 3 trials were compared and ranked. Participants were considered to have a dominant stance only if all 3 trials from that stance were better than the 3 from the contra-lateral side. As an example, if all 3 trials of the LFF track start produced a faster 5 m time than the RFF track start, the participant was considered to manifest a dominant LFF stance. If the results were mixed, participants were considered as equivalent between the LFF and the RFF techniques.

3.3.4 Determination of the dominant limb in the unilateral and bilateral CMJs

A similar technique was employed to determine the dominant foot for the unilateral and the bilateral CMJs. While vertical jump height was collected, in order to have a consistent measure of comparison for both the unilateral and bilateral CMJs, net vertical take-off impulse was used. A participant was deemed as having a dominant left or right foot for the unilateral CMJs if all 3 trials for one foot displayed higher impulse recordings than all 3 trials of the other foot. If there were mixed values, a participant was labeled as having equivalent performances.

For the bilateral CMJs, one foot had to exhibit greater impulse recordings than the other foot for all 3 of the top trials. Again, if there was a mixture of values, they were labeled as being equivalent.

3.3.5 Diving preference and foot preference questionnaires

Diving preferences were assessed using a custom questionnaire, which determined previous swimming experience, preferred dive technique, and average practice time spent on dives. The Waterloo Footedness Questionnaire – Revised (WFQ-R) was used to assess foot preferences for each participant (Elias et al., 1998). In the WFQ-R, foot preference was assessed for object manipulation (questions 1,3,5,7, and 9) and support for an activity (questions 2, 4, 6, 8, and 10).

Scores of -2, -1, 0, 1, and 2 were assigned to responses left always, left usually, both feet equally, right usually, and right always, respectively. The full questionnaire can be seen in Appendix B.

A participant was deemed to be left or right footed for overall foot preference if their total score for all the questions was less than -4 or greater than 4. This range of scores meant that more than half of the questions were answered with a preference for one foot over the other. Similarly, each participant was deemed as being left or right footed for the manipulating foot preference (questions 1, 3, 5, 7, and 9) or supporting foot preference (questions 2, 4, 6, 8, or 10) if their score was less than -2 or greater than 2. Scores between -4 and 4 for overall foot preference or between -2 and 2 for manipulating and supporting foot preference were deemed as having an equivalent preference for the left and right foot.

3.4 Statistical Analysis

Each participant performed 5 track starts for each stance for both the pre-intervention test and the post-intervention test. The best 3 dives of each stance based on 5 m time were retained for analysis. A series of repeated measures analysis of variance (ANOVA) was used to evaluate differences in dive performances between the LFF and RFF stances, between the pre-intervention test and the post-intervention test, and interaction effects between stances and testing sessions.

Additionally, a series of Chi-square analyses were performed to determine relationships between the following variables and the dominant track start stance: the preferred track start stance, the dominant limb for the unilateral CMJ, the dominant limb for the bilateral CMJ, the overall preferred foot, the preferred foot for manipulating tasks, and the preferred foot for supportive tasks.

Chapter 4

4 THE EFFECT OF BILATERAL TRAINING ON TRACK START PERFORMANCES

4.1 Introduction

Presentation of the findings has been organized into two sections due to the nature of this study as both a training intervention and an investigation of the relationship of lower limb asymmetry with the competitive swimming track start. Chapter 4 presents the results and discusses the effects of the training intervention on subsequent track start performance. Chapter 5 addresses the relationship of lower limb asymmetry with track start performance.

When looking at this study from the perspective of a training intervention, it was set out to determine whether the left foot forward (LFF) or the right foot forward (RFF) track start would yield a dominant performance and what would happen when both stances of track start were practiced equally. A 7 week training intervention was implemented where both the LFF and the RFF stances were practiced. Kinetic and kinematic data were collected both prior to and following the training intervention.

4.2 Results

4.2.1 LFF vs. RFF track starts

The summary of the track start variables is presented in Table 4.1. The individual repeated measures ANOVA results are reported in appendix C. The 2x2 repeated measures ANOVA revealed no significant stance by time interaction effects for any of the variables. There were significant main effects between the LFF and the RFF stances and between the pre-intervention test and post-intervention test for most variables. Specifically, peak horizontal force (F_{hor}) and horizontal impulse (I_{hor}) were significantly different between the LFF and the RFF stances ($p<.05$). There were also significant differences between the pre- and post-intervention tests ($p<.05$) for peak vertical force (F_{vert}), vertical impulse (I_{vert}), and vertical take-off velocity (V_{vert}). Horizontal velocity (V_{hor}), net velocity (V_{net}), and take off angle (TOA) showed differences both between the pre- and post-interventions and between the LFF and RFF stances ($p<.05$). While results indicated a significant difference between the pre- and post-intervention tests for reaction time (RT), movement time (MT), and block time (BT), the margin of difference was nearly unnoticeable. Time to 5 m was the only variable that resulted in no significant differences either for stance ($p=.18$) or time ($p=.48$), despite the differences in the other variables.

Table 4.1: Means and standard deviations of track start performance variables

Variables	Track Start Stance				Δ
	Left Foot Forward		Right Foot Forward		
	Pre-Intervention Mean ± S.D.	Post-Intervention Mean ± S.D.	Pre-Intervention Mean ± S.D.	Post-Intervention Mean ± S.D.	
5 m Time (s)	2.472 +/- 0.18	2.468 +/- 0.18	2.509 +/- 0.16	2.481 +/- 0.22	
RT(s)	0.194 +/- 0.02	0.186 +/- 0.02	0.194 +/- 0.02	0.187 +/- 0.02	*
MT(s)	0.729 +/- 0.04	0.713 +/- 0.05	0.735 +/- 0.04	0.709 +/- 0.06	*
BT(s)	0.923 +/- 0.05	0.898 +/- 0.06	0.930 +/- 0.05	0.896 +/- 0.07	*
F_{hor} (N/kg)	8.426 +/- 0.96	8.442 +/- 0.83	8.106 +/- 0.85	8.094+/- 1.02	^
F_{vert} (N/kg)	16.707 +/- 1.88	15.700 +/- 2.00	16.714 +/- 1.88	15.962 +/- 2.13	*
I_{hor} (Ns)	213.978 +/- 48.69	207.372 +/- 47.31	196.933 +/- 43.81	196.922 +/- 49.45	^
I_{vert} (Ns)	90.552+/- 62.05	61.023 +/- 63.80	96.212 +/- 61.27	68.486 +/- 72.11	*
V_{hor} (m/s)	3.589 +/- 0.34	3.415 +/- 0.29	3.302 +/- 0.30	3.229 +/- 0.33	*^
V_{vert} (m/s)	1.438 +/- 0.83	0.922 +/- 0.91	1.537 +/- 0.82	1.037 +/- 1.03	*
V_{net} (m/s)	3.941 +/- 0.58	3.637 +/- 0.44	3.710 +/- 0.55	3.508 +/- 0.61	*^
TOA (deg.)	20.709 +/- 9.94	14.221 +/- 12.99	23.647 +/- 10.74	15.897 +/- 14.32	*^

* Significant difference between pre- and post-intervention at p <. 05 level
^ Significant difference between left and right foot forward at p < .05 level
A list of abbreviations is included in the introduction

4.2.2 Left Foot Forward vs. Right Foot Forward Improvements

Upon examination of individual results, a greater number of participants demonstrated improvements in the RFF stance track start when compared to those of the LFF technique. This result was true for MT, BT, TOA, and 5 m time. The threshold for determining improvement following the training intervention was for a participant to exhibit all three of their top trials from the post-intervention test as better than all three of their top trials from their pre-intervention test. As illustrated in figure 4.1 and 4.2, using 5 m time as the key performance criteria, 50% of participants improved in the RFF track start. Only 32% of participants improved with the LFF track start. RT remained relatively static from pre- to post-intervention.

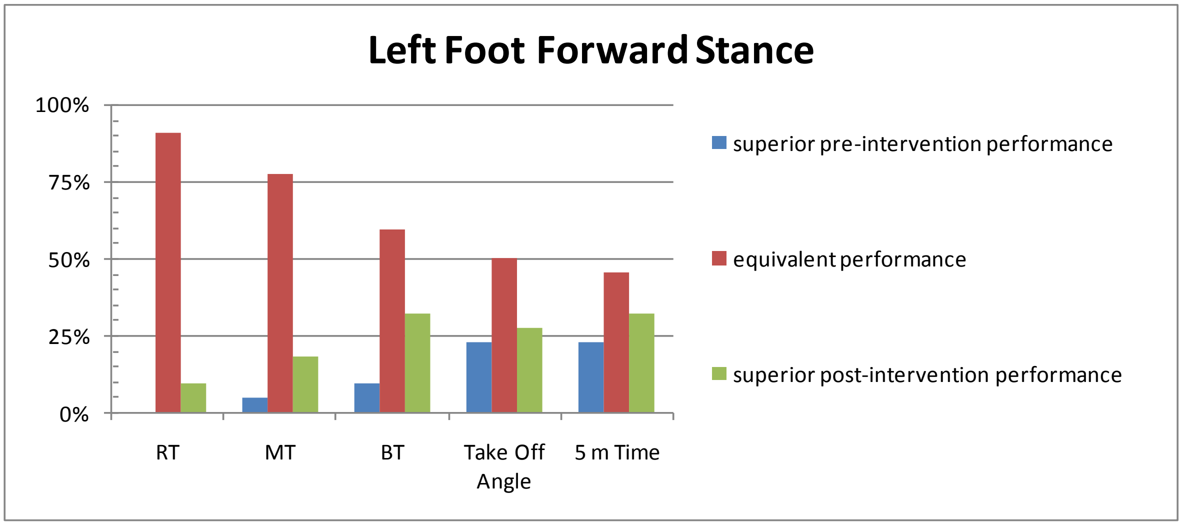

Figure 4.1: Percentage of participants who improved from the pre-intervention to the post-intervention for the left foot forward track start

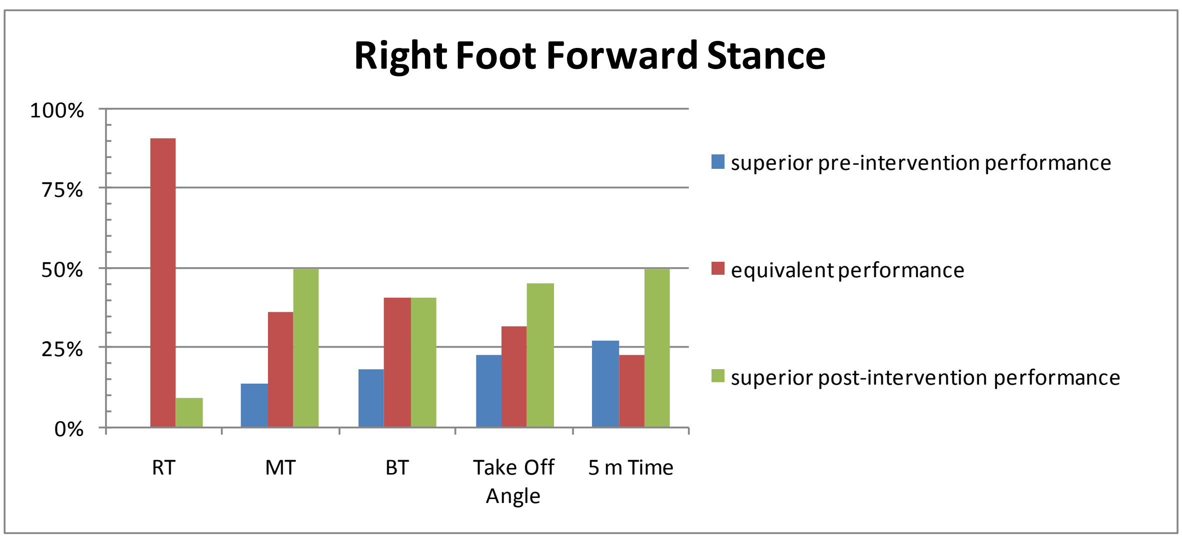

Figure 4.2: Percentage of participants who improved from the pre-intervention to the post-intervention for the right foot forward track start

4.2.3 The Influence of Training on Track Start Stances

A Chi-square test was employed to determine the distribution of participants who demonstrated performance differences between the LFF and RFF stances in the track start before and after the training intervention. As seen in Table 4.2 and 4.3, results indicated there was no significant relationship between the dominant track start stance on the pre-intervention test and the dominant stance on the post-intervention test ($\chi^2_{[4]}$=3.38, p=.50). Approximately one third of the participants changed from exhibiting a dominant LFF or RFF track start on the pre-intervention test to performing equally well between the stances following the training intervention. Conversely, nearly one third of participants shifted from having equivalent performances on the pre-intervention test to having a dominant LFF or RFF track start on the post-intervention test. Close to one third of the participants demonstrated no change in the dominant track start stance following the training intervention.

Table 4.2: Agreements between the pre-intervention track start stance and the post-intervention track start stance

		Post-Intervention Stance			
		Left Foot Forward	**Equivalent**	**Right Foot Forward**	**Total**
Pre-Intervention Stance	**Left Foot Forward**	1 (4.5%)	5 (22.7%)	2 (9.1 %)	**8 (36.4%)**
	Equivalent	5 (22.7%)	5 (22.7%)	2 (9.1%)	**12 (54.5%)**
	Right Foot Forward	0 (0.0%)	1 (4.5%)	1 (4.5%)	**2 (9.1%)**
	Total	**6 (27.3%)**	**11 (50%)**	**5 (22.7%)**	**22 (100.0%)**

Table 4.3: Track start stance changes from the pre- to post-intervention

Type of Stance Change								
Number that switched sides		**Number that became symmetrical**		**Number that became asymmetrical**		**Number that exhibited no training effect**		
Left to Right	Right to Left	Left to Equivalent	Right to Equivalent	Equivalent to Left	Equivalent to Right	Left to Left	Right to Right	Equivalent to Equivalent
2	0	5	1	5	2	1	1	5
9.10%		**27.30%**		**31.80%**		**31.80%**		

4.3 Discussion

4.3.1 Overall Track Start Performances Following the Training Intervention

While the results revealed no significant differences in the track start performance (time to 5 m) between the pre-intervention test and the post-intervention test conditions, other kinetic and kinematic variables collected on the track starts did display differences. In general, no significant changes were observed in the horizontal components of the force profile (F_{hor} & I_{hor}). However a significant reduction in the vertical components was evident following the training intervention (F_{vert}, I_{vert}, & V_{vert}). These lower values for the vertical components contributed to the lower TOA on the post-intervention test.

It was hypothesized that following the 7 week training period, there would be a significant improvement on the 5 m time for both the LFF and the RFF track starts. This expectation was based on results of a similar study conducted by Blanksby et al. (2002). In their study, elite level participants underwent a 6 week period of specific dive start training. Each training session included 5 trials of the preferred grab start technique and 10 trials of either the handle start or the track start depending on group condition. Regardless of preferences, the elite participants improved on all starting techniques following the training intervention. However, the results from the current study found no improvement in 5m time for either the LFF or the RFF track start. These results are more in agreement with findings reported by Breed and Young (2003) where they investigated the influence of resistance training on the grab, swing, and track starts. In addition to strength training, the intervention included one session per week of dive start practice due to their use of novice participants. While they found significant improvements in the take-off velocity, take-off angle, and horizontal impulse for the track start, these differences did not translate to significant differences in the criterion performance variable of total time to water entry. Indeed, Vilas-Boas, Cruz, Sousa, Conceição, and Carvalho (2000) suggested that the underwater portion of the dive may be more important than the out of water phases (block and flight). They compared 3 popular starting techniques (the front weighted track start, the rear weighted track start, and the grab start), and they found significant differences between kinematic variables on the block and in the air for the three techniques. However, as soon as the swimmers completed the underwater phase of the dive start, these differences no longer existed. Hence, the advantage gained from the superior action on the starting block may be negated by a poor underwater performance. Taking these findings into account, it is possible that any improvements ascertained from the 7 week training program may have been masked by slight variations in body motion and trajectories underwater. This study attempted to limit possible variations in the underwater movement by only requiring participants to hold the streamlined glide position upon water entry.

Even though there were no significant improvements in 5 m time following the intervention, other kinematic and kinetic variables measured for the track start showed significant differences. Most notable was the difference in the breakdown of horizontal and vertical forces of the track start. While F_{hor} and I_{hor} did not change significantly, F_{vert} and I_{vert} were significantly lower on the post-intervention test. While it seems that a reduction in force would result in a slower start, the reduction in vertical force may actually relate to improved technique since TOA was also significantly reduced. Because the goal of the dive start is to project the body horizontally, it seems logical that a take-off angle closer to the horizontal would be ideal. Research tends to support the idea that the ideal take-off angle for the start should be approximately 10 degrees (Arellano, Llana, Tella, Morales, & Mercade, 2005; Hobbie, 1980; Lyttle & Benjanuvatra, 2006; Miller et al., 2003). Given this accepted value, the participants in this study showed significant improvements towards the ideal TOA. The average TOA for the LFF track start decreased from 20.7 degrees on the pre-test to 14.2 degrees on the post-test, and TOA for the RFF start decreased from 23.7 degrees to 15.9 degrees following the training intervention. This result suggests that the participants adopted a learning strategy over the course of the study. In order to achieve the desired TOA, they reduced the vertical component of their dives instead of increasing the horizontal force components to achieve more horizontal velocity. The end result was less expenditure of energy on the block with the same time to 5 m, which may be beneficial for swimming races.

While improvements to technique did not result in faster times to 5 m, this result does not mean that the track start was not more proficient following the training intervention. The 5 m time measurement was limited by the fact that dive depth was not taken in to account. Given the same time to 5 m but with differing depths (i.e., one dive goes deep and the other one is shallow), a shallow dive would require less time and energy to reach the surface for the swimming portion of the race. In that sense, it may have been beneficial to measure the underwater trajectory following water entry. Another limitation of the 5 m time measurement stems from the act of just gliding with no kicking motions upon entering the water. While this limitation helped to ensure that time to 5 m was not affected by extraneous body motion, it may have limited the ability to measure times at distances further than 5 m. By including a kick with a normal break-out procedure and an additional time measurement at a further distance than 5 m, perhaps the differences due to steeper dive angles may have been more readily seen.

Because the repeated measure ANOVA was used to examine changes on the group level, it may not have been sensitive enough to detect marginal changes in performance following the training intervention. Swimming is a sport where a margin of .01 s can mean the difference between winning and losing. Therefore, the results were further examined on the individual level. The threshold for determining improvement following the training intervention was for a participant to exhibit all three of their top trials from the post-intervention test as better than all three of their top trials from their pre-intervention test. For the RFF track starts, 50% of participants had a faster 5 m time in the post-intervention test while only 32% of LFF track starts improved following training (see Figures 4.1 and 4.2). Six of these participants improved only their RFF track start, 2 improved just their LFF track start, and 5 improved both their LFF and their RFF track start. For these participants, the training protocol and time frame was sufficient to produce improvements in technique and subsequently faster times to 5 m. The discrepancy in improvements between the two stances may be explained by the fact that more participants exhibited a superior performance with their LFF track start (n=8) prior to training than with the RFF track start (n=2). It is possible that a greater number of participants were already proficient at the LFF technique, and there was less room for improvement than with the RFF stance.

4.3.2 The influence of Training on Track Start Stances

In addition to the changes seen in the kinetic and kinematic variables of the track start, the results of this study also showed changes in the dominant track start stances following the training intervention. The term dominance was used here to describe the stance that produced superior track start performance. Of the 22 participants, 15 exhibited a change in their dominant stance, as measured by the stance that yielded a faster time to 5 m. These stance changes included shifts from a LFF or RFF bias to equivalent performances, shifts from equivalent performances to a LFF or RFF bias, and shifts from one bias to the other. For the 10 participants who initially demonstrated a dominant LFF or RFF stance, 6 shifted their dominant stance to being symmetrical between the LFF and RFF, 2 switched sides completely to the opposite stance being dominant, and 2 exhibited no stance change. Conversely, for 7 of the 12 participants who started out performing equally well with both the LFF and the RFF track start, a dominant LFF or RFF stance emerged following the training intervention. The remaining 5 of 12 maintained equivalent LFF and the RFF track starts.

Because the training intervention involved training both the LFF and RFF track starts equally, it was expected that the previously un-trained stance would become more proficient. Blanksby et al. (2002) found that even among elite athletes, after a 6 week training intervention, both the preferred and non-preferred starting techniques improved. Despite exhibiting a dominant stance that matched their preferred stance on the pre-intervention test, 6 of 10 participants displayed equivalent LFF and RFF track start performances on the post-intervention test. For these participants, the 7 week training intervention was sufficient for their non-preferred and less proficient stance to match their better trained, preferred counterpart. Given more time and practice, it may be possible that the non-preferred track start is actually superior to the preferred technique. Certainly this result gives credence to the idea that dive start practice should receive more time and attention during normal swim training sessions. Also, coaches and swimmers should experiment with different dive techniques to find the one that is best for them.

It was expected that participants who exhibited a performance bias towards the LFF or the RFF track start would become more symmetrical following a training intervention which practiced both stances equally. Also, it was expected that those who began the study with equivalent performances would maintain their symmetry following the training intervention. However, for 7 out of 12 participants who began with equivalent LFF and RFF track start performances, equal training of both techniques resulted in one stance being superior to the other stance. It is unclear why this result may have occurred, but one possible explanation could be related to contra-lateral training effects. Haaland and Hoff (2003) found that soccer skills for both legs improved following an 8 week training intervention which emphasized training of the non-dominant left leg. All participants were right leg dominant. The authors suggested that by training the non-dominant, and previously un-trained left leg, more attention had to be paid to skills in the training situations. They also suggest that this increased attention was a potential explanation for improvements in the right leg, which had not been training those skills for the length of the intervention. Perhaps for the current study, more attention was required to perform and train the non-preferred track start. This increased attention paired with concurrent training of the preferred track start may have been sufficient for the preferred track start to emerge as superior to the non-preferred track start following the training intervention. Certainly this seems a logical explanation because 7 of 12 participants emerged with a dominant stance matching their preferred stance following training despite exhibiting equivalent LFF and RFF track starts on the pre-intervention test (see Table C.6 in appendix C). It may be that dive preference and lower limb asymmetry may link to greater dive start performance.

Chapter 5

5 THE RELATIONSHIP BETWEEN LOWER LIMB ASYMMETRY AND TRACK START PERFORMANCE

5.1 Introduction

This study set out to determine whether the dominant track start stance was related to various measures of lower limb asymmetry. This study also set out to determine what training effects would occur when both the LFF and the RFF track starts were practiced equally. A 7 week training intervention was implemented for this purpose. Different measures of lower limb asymmetry were collected, with the following relationships examined: the preferred track start stance with the dominant track start stance, CMJ performance with track start preference and performance, and foot preference with track start preference and performance.

5.2 Results

5.2.1 Preferred Track Start Stance vs. Dominant Track Start Stance

A Chi-square statistic was employed to determine the distribution of participants who demonstrated performance differences between the preferred track start stance and the dominant track start stance before and after the training intervention. Results revealed a significant relationship between preference and performance for the pre-intervention test ($\chi^2_{[2]}$= 6.71, p=.04), with 41% of the stance preferences accurately predicting dominant stance performances. Following the training intervention, the strength of this relationship slightly increased ($\chi^2_{[2]}$=7.77, p=.02), with 45% of the stance preferences accurately predicting dominant performance.

Table 5.1: Agreements between the preferred track start stance and the dominant track start stance

Dominant Track Stance		Preferred Track Stance		
		Left Foot Forward	**Right Foot Forward**	**Total**
Pre-Intervention	**Left Foot Forward**	7 (31.8%)	1 (4.5%)	**8 (36.4%)**
	Equivalent	5 (22.7%)	7 (31.8%)	**12 (54.5%)**
	Right Foot Forward	0 (0.0%)	2 (9.1%)	**2 (9.1%)**
	Total	**12 (54.5%)**	**10 (45.5%)**	**22 (100.0%)**
Post-Intervention	**Left Foot Forward**	6 (27.3%)	0 (0.0%)	**6 (27.3%)**
	Equivalent	5 (22.7%)	6 (27.3%)	**11 (50.0%)**
	Right Foot Forward	1 (4.5%)	4 (18.2%)	**5 (22.7%)**
	Total	**12 (54.5%)**	**10 (45.5%)**	**22 (100.0%)**

5.2.2 Measures of Asymmetry vs. Track Start Performance

Prior to the training intervention, 3 different measures of asymmetry were collected, and their relationship with track start performance was reviewed. As illustrated in Table 5.2, the results of the Chi-square analyses indicated that no relationship existed between foot preference (overall, manipulative, or supportive) and dominant stance for the track start both prior to and following the training intervention ($p>.05$). Results also showed no significant relationship between the dominant limb for the unilateral CMJ and the dominant track stance on both the pre- and post-intervention tests ($p>.05$). Similarly, no significant relationship was found between the dominant limb for the bilateral CMJ and the dominant track stance on the pre- and post-intervention tests ($p>.05$). While none of the relationships reached a significant level, the strength of all the relationships increased in the post-intervention test. For further information, full contingency tables can be seen in appendix C.

Table 5.2: Results of the Chi-square analyses between the measures of lower limb asymmetry and the dominant track start stance

Relationship	Pearson χ^2	Significance Level
Pre-Intervention Dominant Track Stance with:		
Overall foot preference	$\chi^2_{[2]}$=1.07	P=.59
Manipulating foot preference	$\chi^2_{[2]}$=0.71	P=.70
Supporting foot preference	$\chi^2_{[4]}$=0.50	P=.97
Unilateral CMJ foot	$\chi^2_{[4]}$=1.48	P=.83
Bilateral CMJ foot	$\chi^2_{[4]}$=1.67	P=.80
Post-Intervention Dominant Track Stance with:		
Overall foot preference	$\chi^2_{[2]}$=3.35	P=.19
Manipulating foot preference	$\chi^2_{[2]}$=2.04	P=.36
Supporting foot preference	$\chi^2_{[4]}$=3.46	P=.48
Unilateral CMJ foot	$\chi^2_{[4]}$=5.40	P=.25
Bilateral CMJ foot	$\chi^2_{[4]}$=4.17	P=.38

5.2.3 Measures of Asymmetry vs. Track Start Preference

Chi-square tests were also run to determine the distribution of differences between the preferred track start stance and each measure of asymmetry. The results of the Chi-square analyses indicated that no relationship existed between an individual's foot preference (overall, manipulative, or supportive) and their preferred track stance [($\chi^2_{[1]}$= 1.18, p=.28), ($\chi^2_{[1]}$=.83, p=.36), and ($\chi^2_{[2]}$=.15, p=.93) respectively]. Similarly, the preferred track stance was shown to be unrelated to the dominant foot for the unilateral CMJ and the dominant foot for the bilateral CMJ [($\chi^2_{[2]}$=.49, p=.78), and ($\chi^2_{[2]}$=1.76, p=.42) respectively].

Table 5.3: Agreements between the overall preferred foot, the manipulative preferred foot, and the supportive preferred foot and the preferred track start stance

		Preferred Track Stance		
		Left Foot Forward	**Right Foot Forward**	**Total**
Overall Preferred Foot	**Left Foot**	0 (0.0%)	0 (0.0%)	**0 (0.0%)**
	Mixed	5 (22.7%)	2 (9.1%)	**7 (31.8%)**
	Right Foot	7 (31.8%)	8 (36.4%)	**15 (68.2%)**
	Total	**12 (54.5%)**	**10 (45.5%)**	**22 (100.0%)**
Manipulative Preferred Foot	**Left Foot**	0 (0.0%)	0 (0.0%)	**0 (0.0%)**
	Mixed	3 (13.6%)	1 (4.5%)	**4 (18.2%)**
	Right Foot	9 (40.9%)	9 (40.9%)	**18 (81.8%)**
	Total	**12 (54.5%)**	**10 (45.5%)**	**22 (100.0%)**
Supportive Preferred Foot	**Left Foot**	1 (4.5%)	1 (4.5%)	**2 (9.1%)**
	Mixed	4 (18.2%)	4 (18.2%)	**8 (36.4%)**
	Right Foot	7 (31.8%)	5 (22.7%)	**12 (54.5%)**
	Total	**12 (54.5%)**	**10 (45.5%)**	**22 (100.0%)**

Table 5.4: Agreements between the unilateral and bilateral CMJs and the preferred track start stance

		Preferred Track Stance		
		Left Foot Forward	**Right Foot Forward**	**Total**
Unilateral CMJ Foot	**Left Dominant**	4 (18.2%)	2 (9.1%)	**6 (27.3%)**
	Equivalent	7 (31.8%)	7 (31.8%)	**14 (63.6%)**
	Right Dominant	1 (4.5%)	1 (4.5%)	**2 (9.1%)**
	Total	**12 (54.5%)**	**10 (45.5%)**	**22 (100.0%)**
Bilateral CMJ Foot	**Left Dominant**	4 (18.2%)	3 (13.6%)	**7 (31.8%)**
	Equivalent	3 (13.6%)	5 (22.7%)	**8 (36.4%)**
	Right Dominant	5 (22.7%)	2 (9.1%)	**7 (31.8%)**
	Total	**12 (54.5%)**	**10 (45.5%)**	**22 (100.0%)**

5.3 Discussion

5.3.1 Track Start Preference vs. Track Start Performance

Results indicated that a swimmer's preferred track start stance was related to their dominant track stance on both the pre-intervention test and the post-intervention test [($\chi^2_{[2]}$= 6.71, p=.04), and ($\chi^2_{[2]}$=7.77, p=.02) respectively]. That is, the limb that a swimmer chose to place in the forward position on the starting block had a significant relationship with the stance that yielded the fastest time to 5 m. As can be seen in table 5.1, 41% of the participants performed better with their preferred stance prior to the training intervention, and 45% performed better with their preferred stance on the post-intervention test.

It was expected that prior to the training intervention there would be a significant relationship between preference and performance. Because the swimmers were likely to practice their preferred dive more often than other techniques in their general swimming training, it was thought that they would also perform best with this technique. This assumption was supported by findings of Welcher and George (1998), where they found a significant correlation between the preferred start and the start with which a swimmer had the most experience. Research also tends to support the notion that swimmers perform best at the technique that they practice the most (Blanksby et al., 2002; Kruger et al., 2003).

While the results of the current study show that the swimmers tended to perform best with their preferred track stance, this was not a perfect relationship. Approximately 50% of participants performed equally well or better with their non-preferred track start stance over their preferred stance. When comparing technical preference with overall performance, another study reported similar results. Mills and Gehlsen (1996) reported that their male participants generated greater vertical velocity, had less drag at water entry, and faster gliding speed underwater with the pike swimming start over the flat start, even though half of these participants did not prefer this technique. It was suggested that the swimmers in their study listed a preference for the slower flat start over the superior pike start because they had more practice and were more confident with the flat start. While Mills and Gehlsen (1996) were comparing two starting techniques that had differing biomechanical actions, their results and reasoning may still be applicable to the current study. For the current study, participants may have listed a preference for a particular stance not necessarily because it was the superior stance but because it was the one with which they were most comfortable. Perhaps with more practice and familiarity, however, the faster technique could then become the preferred one.

Considering these findings, it seems Welcher and George's (1998) assessment of the relationship between preference and performance was correct. They proposed that preference may not always be the best predictor of start performance, but that swimmers and coaches should experiment with different dive techniques to determine the start that is best for them. On closer inspection of the current results, it becomes clear that only 7 participants had the same dominant track stance on the pre-intervention test as they had on the post-intervention test. Of these 7, only 2 matched their dominant start with their preferred start. The remaining 15 participants had fluctuating performances from the pre-intervention test to the post-intervention test, with 7 accurately matching dominance with preference on the pre-intervention test but not on the post-intervention test, and 8 matching on the post-intervention test but not on the pre-intervention test.

The reason for this fluctuation of agreement between preference and performance remains unclear. A possible explanation stems from the thought that swimmers tend to base their starting preferences on comfort or coach preferences rather than on scientific evidence (Benjanuvatra et al., 2004). As such, the technique a swimmer chooses is not necessarily the one that suits their characteristics and will produce the best results, but it is merely more familiar. This explanation seems plausible in the scope of the current study since more than half of the participants performed equal to or better than their preferred stance with their non-preferred stance before the training intervention.

Another explanation for the lack of agreement between preference and performance lies in the idea that swimmers do not spend adequate time practicing dive starts during their normal swim training. It may be that limited dive start training is not enough for the preferred track start stance to have a significant impact on performance over the non-preferred track start stance for some participants. Seven weeks of training both the LFF and the RFF track starts may have been a sufficient amount of time to bring the previously non-preferred stance up to the same performance level as the preferred stance. Six participants displayed this effect, where their preferred track start matched their dominant track start on the pre-intervention test, but they exhibited equivalent performances between the LFF and the RFF stances on the post-intervention test.

For other participants, it seems that inadequate dive practice in normal swim training may have resulted in neither the preferred nor the non-preferred stance being dominant to the other prior to the intervention. 7 weeks of concentrated dive start training, however, may have been enough time for the preferred stance to emerge as dominant to the non-preferred stance. Eight participants showed this pattern of emergence where they had equivalent LFF and RFF track start performances on the pre-intervention test, but they exhibited a dominant stance matching their preferred stance on the post-intervention test.

Considering the amount of fluctuation over the short 7 week training intervention, it may be beneficial for later studies to extend the training intervention to 10-12 weeks with measurements collected prior to the intervention, halfway through, and following the intervention. In this way, patterns of stance change could be tracked over a longer period of time to see if training effects would remain stable or if the changes would become more distinct. Also, links between track start preferences and performances may be strengthened with greater practice. Because the swimmers had previous training and experience to develop the skill level of one starting technique over another, the 7 week training intervention of this study may not have been long enough to establish a clear relationship between preference and dominance. A longer training intervention may reveal more comprehensive and conclusive results than the shorter intervention implemented for this study.

Since more than two-thirds of the participants changed their dominant stance following the training intervention, it also seems clear that the participants have not been receiving adequate dive start practice during their normal swimming sessions. It is recommended that swimmers practice dive starts more often and with multiple techniques in order to find the technique that is most proficient for them.

5.3.2 CMJ Performance vs. Track Start Preference and Performance

While results indicated that there was a relationship between a swimmer's preferred track stance and their dominant stance, it was also assumed that lower limb asymmetry would be a factor linked to the track start stance. One aspect of lower limb asymmetry that was expected to be related to the track start stance was the dominant take-off limb in a one-legged CMJ and the dominant limb in a two-legged CMJ. The dominant foot was determined by measuring the vertical push-off impulses for unilateral and bilateral CMJs. The limb that created the most impulse in the unilateral CMJ, and the limb that contributed the most towards impulse in the bilateral CMJ were recorded as dominant. Research tends to support the idea that the forward foot creates more force than the rear foot in the track start (Ayalon et al., 1975; Breed & McElroy, 2000; Lyttle & Benjanuvatra, 2006; Miller et al., 2003; Verrier, 1985). As such, it was expected that the foot that created the most impulse in the CMJs would be related to the preferred forward foot in the track start and the dominant track start stance (either LFF or RFF). Results indicated that neither the dominant foot for the unilateral CMJ nor the dominant foot for the bilateral CMJ were significantly related to the preferred forward foot for the track start ($p>.05$). Similarly, the dominant limbs for the unilateral and bilateral CMJs were unrelated to the dominant track start on the pre-intervention test ($p>.05$) or to the dominant track start on the post-intervention test ($p>.05$).

CMJs and dive starts are both complex, explosive skills that utilize lower limb strength for propulsion, so it was expected that CMJ performance would be correlated with track start performance. However, findings of previous studies comparing jumping ability with dive starts have yielded inconclusive results (Arellano et al., 2005; Benjanuvatra et al., 2007; Breed & Young, 2003; Davies, Murphy, Whitty, & Watsford, 2001; De La Fuente, Garcia, & Arellano, 2002; Lee, Huang, Wang, & Lin, 2001; Zatsiorski et al., 1979). While some studies have reported that starting performance is significantly correlated with jumping ability, it is often the case that jumping ability and leg strength do not directly transfer over to dive starts. For example, Breed and Young (2003) initially found that CMJ performance was positively correlated with flight distance for the grab start. Following an 8 week training intervention aimed at and resulting in greater vertical jumping ability and leg strength, flight distance did not subsequently improve. It was suggested that the dive start was more complex than the vertical jump, and as such, improvements in jumping ability would not necessarily transfer over to starting ability. This argument seems to be a logical explanation for the findings of the current study. The vertical jump appears much simpler because the body starts in a standing position, and the legs push against the ground to propel the body upwards in one direction. The track start requires that the participant leans over, staggers their stance, centers their body weight over the front leg, and propels their body at an optimal angle through the air. Not only are the legs involved, but the arms and rest of the body work with the legs to create forward motion. Considering this complexity, it is understandable that unilateral and bilateral CMJ performances were not directly related to track start preference and performance for the current study.

Benjanuvatra et al. (2007) also found that leg strength and jumping ability were not reliable predictors of start performance. They investigated differences in jumping and starting performances between recreational and elite swimmers, and they found that leg strength was not a determining factor for starting efficiency. Despite recording similar vertical and horizontal jumping performances, the elite swimmers produced significantly more horizontal impulse on their dive starts than the recreational swimmers. They also recorded faster 5 m times as a result. It was suggested that it was not just leg strength that determined superior start performance, but it was the better appropriation of leg strength and better coordination patterns that led to faster dives. Considering the complexity of the track start, it seems reasonable that the dominant leg in the CMJs did not predict the dominant stance in the track start for the current study. It is not only the strength of one leg that propels the body forward. It is the action of that leg in conjunction with the other leg, both arms, and the rest of the body that all work together for forward propulsion. While one leg may be stronger than the other, one leg may work better in synergy with the rest of the body to produce a faster track start.

It may be beneficial for further studies to separate out the individual force contributions of the lower limbs on the track start. By doing this, it may be seen which foot contributes more towards the horizontal propulsion of the dive. This may also demonstrate to be a more congruent measure with the impulse recordings collected for the unilateral and bilateral CMJs. Perhaps by comparing the force production of a CMJ with the force production of the track start, a better relationship may be seen between lower leg strength and dive performance.

5.3.3 Foot Preference vs. Track Start Preference and Performance

Prior to the training intervention, the participants in this study listed preferences for the track start, and this was found to be related to their dominant track start. It was also predicted that general lower limb preference would relate to track start preference and performance. In order to measure foot preference, the participants completed the WFQ-R, which assessed overall foot preference, manipulative foot preference (questions 1, 3, 5, 7, and 9), and supportive foot preference (questions 2, 4, 6, 8, and 10) (Elias et al., 1998). Results indicated that foot preference –including overall, manipulative, and supportive – was not related to the preferred track start stance ($p>.05$) or to the dominant track start stance ($p>.05$).

Given that the front leg produces more force than the rear leg in the track start, the front leg was thought to be the manipulative limb. As such, it was anticipated that the forward foot of the dominant track start stance would be correlated with the manipulative preferred limb from the WFQ-R. Alternatively, body weight is centered over the forward foot in the track start, so this foot performs supporting action as well. From this perspective it was conceivable that the preferred supporting limb assessed by the WFQ-R could be related to the forward foot of the dominant track start. Results reflected this confusion between limb responsibilities. Neither the manipulative preferred limb nor the supportive preferred limb was related to the track start participants preferred or to their dominant stance. Indeed, Peters (1988) has suggested that footedness is complicated to measure in the context of athletics because the feet interact with the arms and the rest of the body to complete tasks. The activities listed in the footedness assessment were all relatively simple tasks that required mainly the use of one foot with not much contribution from other parts of the body. As such, it may have been that the preference choices for the WFQ-R would not cross over to track start preference and performance because the actions did not reflect the type of movements required for the track start. Sadeghi et al. (2000) also came to the conclusion that it is difficult to match measures of preference with measures of performance where the legs are concerned because the head, arms, and torso tend to be involved in lower limb activities.

Studies have also shown that preference and performance are task specific, and one does not always determine the other (Armitage & Larkin, 1993; Chapman et al., 1987; Corey et al., 2001; Hart & Gabbard, 1997; Porac & Coren, 1981; Provins, 1997; Rigal, 1992; Sadeghi et al., 2000). Hart and Gabbard (1997) determined that the preferred limb for one task did not necessarily match the preferred limb for another task in their study on stabilizing preferences. They found that the majority of right footers, who stated a left foot preference for stabilizing in bilateral tasks, actually used their right foot for stabilizing in a unilateral task. Even though they listed their left leg as the preferred limb for stabilization, they switched to using their right leg when only one leg was required to complete the action. This links to the notion that foot preference is not constant across all situations.

In a review of motor skill and asymmetry, Provins (1997) suggested that in addition to being task specific, proficiency and preference are also closely related to the amount of training each limb does for a task. The more training the preferred side has for a particular action, the more likely that this limb will also be the one which is more proficient. While these findings were in relation to hand preference, Peters (1988) suggested that training still plays a role in the matching of preference and performance of the lower limbs. However, he elaborated saying that because foot activities are less likely to be over-learned, footedness may not be as universal or strong as handedness. Since preference and performance have been found to be task specific, and the relationship between the two may be affected in part by training, the results of the current study were not surprising. In the current study, it was found that the preferred foot, as assessed by the WFQ-R, was unrelated to the preferred forward foot for the track start. The tasks listed in the WFQ-R may have been too distinct from the actions of the track start to be reflective of the demands of the track start. The preferred foot was also found to be unrelated to the dominant track stance.

While it was hypothesized that each of the measures of lower limb asymmetry would be related to track start performance, only track start preference had any relation to track start performance. This reflects the idea that preference and performance are task specific. Even with two seemingly related tasks, CMJs and dive starts, the results show that performance in one did not reliably predict preference or performance in the other. Furthermore, general lower limb preferences were also found to be unrelated to track stance preferences and track stance performances. Since track stance preference was the only related measure, it may be beneficial for further studies to examine this relationship. In order to see whether training has an effect on preference and performance, participants could be initially separated into experimental groups based on performance differences. For example, those who exhibit equivalent performances between their LFF and RFF stances could be used as a control group that trains both stances equally. Those who exhibit a dominant LFF or RFF stance could be separated into either a group that trains with their preferred stance or a group that trains their non-preferred stance. In this manner, it could be seen whether preference for a particular stance is affected by training, and hopefully better matches between preference and performance could be seen. It is also recommended that swimmers and coaches spend training time practicing multiple dive start techniques to find the technique that is most proficient for each swimmer.

Chapter 6

6 SUMMARY AND CONCLUSIONS

6.1 Summary

In an attempt to optimize the swimming track start, this study examined the relationship between lower limb asymmetry and placement of the front and rear feet in the swimming track start. A 7 week training intervention was implemented to investigate the training effects that would occur as a result of practicing both the LFF and the RFF track starts equally. By practicing the track start using both the LFF and RFF stances, this study sought to determine whether one stance would enable superior track start performances in comparison to the other, and whether the dominant stance would be related to measures of lower limb asymmetry.

Contrary to the hypothesis that dive start performance would improve following a 7 week training intervention, repeated measures ANOVA results indicated that neither the LFF track start nor the RFF track start improved in the criterion measure of 5 m time following training ($F_{[1,21]}$=0.515, p=0.481). The results also indicated that there was no significant performance difference between the LFF or the RFF track starts after 7 weeks of training both techniques equally ($F_{[1,21]}$=1.950, p=.177). . Since the repeated measures ANOVA was used to examine changes on the group level, it may not have been sensitive enough to detect marginal changes in performance. Therefore, these results were further examined on the individual level. For the RFF track starts, 50% of participants had a faster 5 m time in the post-intervention test, and 32% of LFF track starts improved following training.

Furthermore, the ANOVA revealed no significant 5 m performance time differences between the LFF and RFF track starts, but other kinematic and kinetic variables exhibited differences between stances or between testing times. Specifically, F_{hor} and I_{hor} were higher for the LFF track start than the RFF track start (p<.05). F_{vert}, I_{vert}, and V_{vert} were all significantly lower on the post-intervention test as compared to the pre-intervention test (p<.05). V_{hor}, V_{net}, and TOA showed differences both between the pre- and post-interventions and between the LFF and RFF stances (p<.05).

Four different measures of lower limb asymmetry were collected, including track start preference (via a dive preference questionnaire), foot preference (via the WFQ-R), unilateral CMJ performance, and bilateral CMJ performance. A series of Chi-square analyses were run to determine the relationship between lower limb asymmetry and track start performance. The following relationships were investigated: the preferred track start stance with the dominant track start stance, CMJ performance with track start preference and performance, and foot preference with track start preference and performance. It was hypothesized that the preferred track start would produce faster 5 m times than the non-preferred start, and results indicated that participants tended to perform better using their preferred stance both on the pre-intervention test ($\chi^2_{[2]}$= 6.71, p=.04) and on the post-intervention test ($\chi^2_{[2]}$=7.77, p=.02). It was also hypothesized that each of the measures of lower limb asymmetry (including unilateral CMJ performance, bilateral CMJ performance, and foot preference) would be related to track start performance. Contrary to expectations, none of these measures of lower limb asymmetry were related to track start performance (p>.05).

6.2 Conclusions

On the basis of the results in this study, it can be concluded that:

1. On the group level, start performances did not improve in the criterion measure of 5 m time following a 7 week training intervention.
2. On the individual level, a 7 week training intervention was sufficient for 50% of RFF and 32% of LFF track starts to improve in 5 m time.

3. Vertical force, vertical impulse, vertical velocity, and take-off angle were all significantly lower for both the LFF and the RFF track starts following training. This suggests that starting technique became more efficient.
4. The 7 week intervention resulted in a training effect whereby 68% of participants changed their dominant track start stance.
5. Track start preference was significantly related to track start performance.
6. The dominant take-off leg for the unilateral CMJ was unrelated to the dominant track start stance or to the preferred track start stance.
7. The dominant take-off leg for the bilateral CMJ was unrelated to the dominant track start stance or to the preferred track start stance.
8. Overall foot preference, manipulative foot preference, and supportive foot preference were not related to the dominant track start stance or to the preferred track start stance.

6.3 Recommendations for further study

It is recommended that future research endeavors to:

1. Lengthen the training intervention to 10-12 weeks in order to see more conclusive training effects and to more accurately track the pattern of stance changes over time to determine the true dominant stance.
2. Separate out the individual force profiles for each of the feet in the track start in order to determine which foot contributes the most towards the horizontal propulsion of the track start.
3. Use high-speed video taping and motion analysis to track body trajectory and angular changes between joint segments (shoulder, hip, knee, and ankle) in the above water and underwater phases of the dive. In this way, one can determine the effect these factors have on entry angle and distance travelled underwater.

4. Use a more complete force profile to determine the relationship between force production for the track start and force production for CMJs.
5. Further explore the relationship between track start preference and performance, and determine if this relationship can be altered through training.
6. Examine the relationship between track start preference and performance over a range of swimming abilities and experience.

6.4 Recommendations for coaches and swimmers

It is recommended that coaches provide greater time and attention to dive starts in their normal training sessions. Swimmers should also experiment with different dive start techniques in order to find the technique that works best for them.

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APPENDIX A

PARTICIPANT INFORMATION SHEET AND CONSENT FORM

Participant Information Sheet

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An Analysis of Foot Placement on Force Production and Velocity of a Competitive Swimming Track Start

-Participant Information Sheet-

Dear Swimmers and Parents/Guardians of swimmers:

You are invited to participate in a research study at the Uniswim aquatic laboratory in the School of Human Movement and Exercise Science, University of Western Australia. The study will be conducted by Ms. Julie Hardt under the supervision of Mr. Nat Benjanuvatra.

Purpose:

This study aims to examine the relationship between lower limb asymmetry and placement of the front and rear feet in the swimming track start. Asymmetry can be described as a persistent, dominant performance of one limb over another in a motor task, and it will be investigated through one-legged and two-legged counter-movement jumps as well as alternate foot placements on the starting block. By practicing the track start using both the right-foot forward and the left-foot forward stances, this study will examine whether forces on the track start can be optimized by altering foot placement based on asymmetry.

Procedures:

As a participant, you are required to attend three sessions. The first is for a familiarization whereby you will be introduced to the equipment and testing protocols. The second session will be arranged following the familiarization session. The third session will be approximately six to eight weeks following the second session. In each testing session, you will be asked to perform the following tasks in a laboratory at the School of Human Movement and Exercise Science at the University of Western Australia.

1. Track start trials

Before testing, the hip landmark will be identified to represent your center of mass, and marked with a permanent marker. You will then be given a standardized warm-up that includes start practice. Following the warm-up, you will be required to perform five trials of a track start with the left foot forward and five trials of a track start with the right foot forward. Ground reaction force (GRF) and video data will be recorded for each trial.

2. One-legged and two-legged counter-movement jumps (CMJ)

Five complete trials each of the two-legged CMJ, one-legged CMJ with the left leg, and one-legged CMJ with the right leg will be performed in randomized order. For each of the jumping trials, GRF and video data will be recorder. Between trials, you will be provided with as much recovery time as required to prevent the effects of fatigue.

3. Footedness and diving preference questionnaires

You will also be required to complete two questionnaires: the Waterloo Footedness Questionnaire, which assesses foot preference, and general diving preference questionnaire.

Training Intervention:

The 6 week training intervention will be conducted in the final 20 minutes of regular training sessions. You are required to attend a minimum of 16 sessions over the 6 week period. In each of these sessions, eight repeats of the track start with the right leg forward and eight with the left leg forward will be practiced. Feedback will be given when appropriate.

Benefits:

Currently it is unclear how the two lower limbs interact in the production of force on the track start. Therefore, investigations of asymmetry as it relates to force production on a track start could offer insights into optimal foot placement. The results from this study will lead to further understanding of the interaction of force production and asymmetry on the track start.

As and incentive for participation, you will receive a detailed biomechanical analysis of your starts at no cost. You also will be given a written report of the results along with comments from and expert in the field. Generally, opportunity for detailed biomechanical analysis is limited and can be costly to the athletes.

Possible Risks:

The study examines the lower limb function in activities that are not dangerous. Nevertheless, there will be full supervision from research staff for the duration of the testing period. You may experience some discomfort during the experiment because the tasks are performed at a maximum effort. However, these physical demands are not as high as what you would experience during regular training. It is possible that you may also experience some delayed-onset-muscle-soreness 24-72 hours following testing sessions. This can be minimized with appropriate warm-up and recovery techniques.

Confidentiality of Data:

Personal details and test results will be treated confidentially at all times. The video tapes containing the start and jumping footages will be stored in a locked cupboard at the School of Human Movement and Exercise Science. Individual data will not be identifiable, but collective results may be published.

Subject Rights & Participations:

You are encouraged to discuss your participation with your parents and coaches. Participation in this research is voluntary and you are free to withdraw from the study at any time without prejudice. You can withdraw for any reason and you do not need to justify your decision. If you do withdraw we may wish to retain the data that we have recorded from you but only if you agree, otherwise your records will be destroyed. Your participation in this study does not prejudice any right to compensation that you may have under statute of common law. Additionally, you will not be prejudiced from future programs or discrimination from the coaching staff at the UWA-Uniswim program.

If you withdraw from the study and you are an employee or student at the University of Western Australia (UWA) this will not prejudice your status and rights as employee or student of UWA. If you withdraw from the study and are a patient recruited from one of the affiliated clinics your treatment will not be prejudiced or affected in any way.

If you have any questions, I can be contacted directly on 6488 2437 or via e-mail at natbenj@cyllene.uwa.edu.au. Queries can also be directed to Julie Hardt on 0420 502 925 or email hardtj01@student.uwa.edu.au.

Yours Sincerely,

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Consent Form

An Analysis of Foot Placement on Force Production and Velocity of a Competitive Swimming Track Start

-Consent Form-

I ________________________________, the parent/guardian of ____________________________, hereby give permission for my child to participate in the research study described in the information letter, which explains the nature, risks, demands, and benefits of the study. Any questions that I have regarding the study have been satisfactorily answered. I also understand that I have the right to withdraw my consent and to discontinue from the study at any time without penalty. Any data obtained from the study may be published provided my child's name or other identifying information is not disclosed.

Parent's signature____
Date_______________________

Child's signature_______________________________ Age________
Date_______________________

The Human Research Ethics Committee at the University of Western Australia requires that all participants are informed that, if they have any complaint regarding the manner, in which a research project is conducted, it may be given to the researcher or, alternatively, to the Secretary, Human Research Ethics Committee, Registrar's Office, University of Western Australia, 35 Stirling Highway, Crawley, WA 6009 (telephone number 6488 3703). All study participants will be provided with a copy of the Information Sheet and Consent Form for their personal records.

APPENDIX B

WATERLOO FOOTEDNESS QUESTIONNAIRE – REVISED, DIVE PREFERENCE QUESTIONNAIRE, AND PARTICIPANT INFORMATION

Waterloo Footedness Questionnaire-Revised

Waterloo Footedness Questionairre - Revised

Instructions

Answer each of the following questions as best you can. If you **always** use one foot to perform the described activity, circle **Ra** or **La** (for **right always** or **left always**). If you **usually** use one foot, circle **Ru** or **Lu**, as appropriate. If you use **both** feet **equally** often, circle **Eq**.

Please do not simply circle one answer for all questions, but imagine yourself performing each activity in turn, and then mark the appropriate answer. If necessary, stop and pantomime the activity.

1.	Which foot would you use to kick a stationary ball at a target straight in front of you?	**La**	**Lu**	**Eq**	**Ru**	**Ra**
2.	If you had to stand on one foot, which foot would it be?	**La**	**Lu**	**Eq**	**Ru**	**Ra**
3.	Which foot would you use to smooth sand at the beach?	**La**	**Lu**	**Eq**	**Ru**	**Ra**
4.	If you had to step up onto a chair, which foot would you place on the chair first?	**La**	**Lu**	**Eq**	**Ru**	**Ra**
5.	Which foot would you use to stomp on a fast-moving bug?	**La**	**Lu**	**Eq**	**Ru**	**Ra**
6.	If you were to balance on one foot on a railway track, which foot would you use?	**La**	**Lu**	**Eq**	**Ru**	**Ra**
7.	If you wanted to pick up a marble with your toes, which foot would you use?	**La**	**Lu**	**Eq**	**Ru**	**Ra**
8.	If you had to hop on one foot, which foot would you use?	**La**	**Lu**	**Eq**	**Ru**	**Ra**
9.	Which foot would you use to help push a shovel into the ground?	**La**	**Lu**	**Eq**	**Ru**	**Ra**
10.	During relaxed standing, people initially put most of their weight on one foot, leaving the other slightly bent. Which foot do you put most of your weight on first?	**La**	**Lu**	**Eq**	**Ru**	**Ra**
11.	Is there any reason (i.e. injury) why you have changed your foot preference for any of the above activities?	**Yes**	**No**	(circle one)		
12.	Have you been given special training or encouragement to use a particular foot for certain activities?	**Yes**	**No**	(circle one)		
13.	If you have answered YES for either questions 11 or 12, please explain:					

Dive Preference Questionnaire

Swimming Experience and Dive Preference Questionnaire

What is your highest level of swimming participation:

recreational and club level	state competitions	national competitions	international competitions

How many years have you participated in competitive swimming:	

What is your preferred starting technique: circle one

grab start	track start	track start - slingshot

Which foot do you prefer to put forward on the track start: circle one

left foot	right foot

How frequently do you practice your starts: circle one

less than one session per week	one or two sessions per week	three to four sessions per week	five or more sessions per week

On average, how much time do you spend per session praticing starts (in minutes):	

How would you rate the effectiveness of your start: circle one

Poor	Below average	Average	Above average	Excellent

Participant Information

Participant Information

Last name:		First name:				Middle Initial:	
Date of birth:	dd / mm / yyyy		Gender:	male		female	

Street address:			Suburb:		
Post Code:		Telephone Numbers:	home	work	mobile
Email address:					

Please list and explain any major injuries or medical problems you have had related to your lower limbs:

APPENDIX C

ADDITIONAL RESULTS

Repeated measures ANOVA results

Table C. 1: Repeated measures ANOVA results comparing forward foot stance and pre- and post-intervention tests for the kinetic and kinematic track start variables

Variable	Interaction effect		Time main effect		Stance main effect	
	F value (1, 21)	Significance level	F value (1, 21)	Significance level	F value (1, 21)	Significance level
5m Time	0.749	0.397	0.515	0.481	1.950	0.177
RT	0.032	0.860	6.359	0.020*	0.231	0.636
MT	1.346	0.259	6.226	0.021*	0.041	0.842
BT	0.792	0.384	7.865	0.011*	0.120	0.732
F_{hor}	0.017	0.898	0.000	0.990	7.763	0.011*
F_{vert}	0.524	0.477	4.871	0.039*	0.293	0.594
I_{hor}	3.610	0.071	1.262	0.274	48.470	0.000**
I_{vert}	0.086	0.773	8.838	0.007**	2.785	0.110
V_{hor}	4.323	0.050	18.667	0.000**	44.520	0.000**
V_{vert}	0.024	0.878	9.580	0.005**	2.411	0.135
V_{net}	3.156	0.090	14.016	0.001**	12.309	0.002**
TOA	0.694	0.414	8.868	0.007**	4.944	0.037*

*indicates significant difference at p<.05 level
**indicates significant difference at p<.01 level

Preferred foot vs. dominant track stance Chi-square results

Table C. 2: Agreements between the overall preferred foot, the manipulating preferred foot, and the supporting preferred foot and the dominant track start stance for the pre-intervention test [($\chi^2_{[2]}$=1.07, p=.59), ($\chi^2_{[2]}$=.71, p=.70), and ($\chi^2_{[4]}$=.50, p=.97) respectively].

		Dominant Track Stance: Pre-Intervention			
		Left Foot Forward	**Equivalent**	**Right Foot Forward**	**Total**
Overall Preferred Foot	**Left Foot**	0 (0.0%)	0 (0.0%)	0 (0.0%)	**0 (0.0%)**
	Mixed	3 (13.6%)	4 (18.2%)	0 (0.0%)	**7 (31.8%)**
	Right Foot	5 (22.7%)	8 (36.4%)	2 (9.1%)	**15 (68.2%)**
	Total	**8 (36.4%)**	**12 (54.5%)**	**2 (9.1%)**	**22 (100.0%)**
Manipulating Preferred Foot	**Left Foot**	0 (0.0%)	0 (0.0%)	0 (0.0%)	**0 (0.0%)**
	Mixed	2 (9.1%)	2 (9.1%)	0 (0.0%)	**4 (18.2%)**
	Right Foot	6 (27.3%)	10 (45.5%)	2 (9.1%)	**18 (81.8%)**
	Total	**8 (36.4%)**	**12 (54.5%)**	**2 (9.1%)**	**22 (100.0%)**
Supporting Preferred Foot	**Left Foot**	1 (4.5%)	1 (4.5%)	0 (0.0%)	**2 (9.1%)**
	Mixed	3 (13.6%)	4 (18.2%)	1 (4.5%)	**8 (36.4%)**
	Right Foot	4 (18.2%)	7 (31.8%)	1 (4.5%)	**12 (54.5%)**
	Total	**8 (36.4%)**	**12 (54.5%)**	**2 (9.1%)**	**22 (100.0%)**

Table C. 3: Agreements between the overall preferred foot, the manipulating preferred foot, and the supporting preferred foot and the dominant track start stance for the post-intervention test [($\chi^2_{[2]}$=3.35, p=.19), ($\chi^2_{[2]}$=2.04, p=.36), and ($\chi^2_{[4]}$=3.46, p=.48) respectively].

		Dominant Track Stance: Post-Intervention			
		Left Foot Forward	**Equivalent**	**Right Foot Forward**	**Total**
Overall Preferred Foot	**Left Foot**	0 (0.0%)	0 (0.0%)	0 (0.0%)	**0 (0.0%)**
	Mixed	3 (13.6%)	4 (18.2%)	0 (0.0%)	**7 (31.8%)**
	Right Foot	3 (13.6%)	7 (31.8%)	5 (22.7%)	**15 (68.2%)**
	Total	**6 (27.3%)**	**11 (50.0%)**	**5 (22.7%)**	**22 (100.0%)**
Manipulating Preferred Foot	**Left Foot**	0 (0.0%)	0 (0.0%)	0 (0.0%)	**0 (0.0%)**
	Mixed	2 (9.1%)	2 (9.1%)	0 (0.0%)	**4 (18.2%)**
	Right Foot	4 (18.2%)	9 (40.9%)	5 (22.7%)	**18 (81.8%)**
	Total	**6 (27.3%)**	**11 (50.0%)**	**5 (22.7%)**	**22 (100.0%)**
Supporting Preferred Foot	**Left Foot**	0 (0.0%)	2 (9.1%)	0 (0.0%)	**2 (9.1%)**
	Mixed	3 (13.6%)	4 (18.2%)	1 (4.5%)	**8 (36.4%)**
	Right Foot	3 (13.6%)	5 (22.7%)	4 (18.2%)	**12 (54.5%)**
	Total	**6 (27.3%)**	**11 (50.0%)**	**5 (22.7%)**	**22 (100.0%)**

Dominant track stance vs. dominant CMJ foot Chi-square results

Table C. 4: Agreements between the dominant track start stance based on 5m time for the pre- and post-intervention tests and the dominant unilateral CMJ foot based on push-off impulse recordings [($\chi^2_{[4]}$=1.48, p=.83) and ($\chi^2_{[4]}$=5.40, p=.25) respectively].

		Dominant Unilateral CMJ Foot			
		Left Dominant	Equivalent	Right Dominant	Total
Dominant Track Stance: Pre-Intervention	**Left Foot Forward**	2 (9.1%)	5 (22.7%)	1 (4.5%)	**8 (36.4%)**
	Equivalent	4 (18.2%)	7 (31.8%)	1 (4.5%)	**12 (54.5%)**
	Right Foot Forward	0 (0.0%)	2 (9.1%)	0 (0.0%)	**2 (9.1%)**
	Total	**6 (27.3%)**	**14 (63.6%)**	**2 (9.1%)**	**22 (100.0%)**
Dominant Track Stance: Post-Intervention	**Left Foot Forward**	2 (9.1%)	4 (18.2%)	0 (0.0%)	**6 (27.3%)**
	Equivalent	4 (18.2%)	5 (22.7%)	2 (9.1%)	**11 (50.0%)**
	Right Foot Forward	0 (0.0%)	5 (22.7%)	0 (0.0%)	**5 (22.7%)**
	Total	**6 (27.3%)**	**14 (63.6%)**	**2 (9.1%)**	**22 (100.0%)**

Table C. 5: Agreements between the dominant track start stance based on 5m time for the pre- and post-intervention tests and the dominant bilateral CMJ foot based on push-off impulse recordings [($\chi^2_{[4]}$=1.67, p=.80) and ($\chi^2_{[4]}$=4.17, p=.38) respectively].

		Dominant Bilateral CMJ Foot			
		Left Dominant	Equivalent	Right Dominant	Total
Dominant Track Stance: Pre-Intervention	Left Foot Forward	3 (13.6%)	2 (9.1%)	3 (13.6%)	**8 (36.4%)**
	Equivalent	4 (18.2%)	5 (22.7%)	3 (13.6%)	**12 (54.5%)**
	Right Foot Forward	0 (0.0%)	1 (4.5%)	1 (4.5%)	**2 (9.1%)**
	Total	**7 (31.8%)**	**8 (36.4%)**	**7 (31.8%)**	**22 (100.0%)**
Dominant Track Stance: Post-Intervention	Left Foot Forward	2 (9.1%)	2 (9.1%)	2 (9.1%)	**6 (27.3%)**
	Equivalent	2 (9.1%)	4 (18.2%)	5 (22.7%)	**11 (50.0%)**
	Right Foot Forward	3 (13.6%)	2 (9.1%)	0 (0.0%)	**5 (22.7%)**
	Total	**7 (31.8%)**	**8 (36.4%)**	**7 (31.8%)**	**22 (100.0%)**

Asymmetry measure distributions

Table C. 6: Distribution of different measures of asymmetry for each participant

Code	Preferred Track Start Stance	Dominant Track Stance Pre-Intervention	Dominant Track Stance Post-Intervention	Overall Foot Preference	Manipulating Foot Preference	Supporting Foot Preference	Dominant Foot - Unilateral Impulse	Dominant Foot - Bilateral Impulse
101	Right	Equal	Right	Right	Right	Right	Equal	Equal
102	Right	Equal	Right	Right	Right	Right	Equal	Left
104	Right	Right	Right	Right	Right	Right	Equal	Equal
105	Right	Equal	Equal	Right	Right	Equal	Equal	Equal
106	Right	Left	Right	Right	Right	Equal	Equal	Left
107	Right	Equal	Equal	Right	Right	Equal	Right	Equal
108	Right	Equal	Equal	Right	Right	Right	Left	Left
109	Left	Equal	Left	Right	Right	Right	Equal	Right
111	Left	Left	Equal	Right	Right	Right	Left	Left
112	Right	Right	Equal	Right	Right	Equal	Equal	Right
113	Left	Left	Equal	Equal	Equal	Equal	Right	Right
114	Right	Equal	Equal	Equal	Right	Left	Equal	Equal
115	Left	Left	Equal	Right	Right	Right	Left	Right
116	Left	Left	Equal	Equal	Right	Left	Equal	Equal
118	Right	Equal	Equal	Equal	Equal	Right	Left	Right
119	Left	Equal	Left	Equal	Equal	Equal	Equal	Left
120	Left	Equal	Left	Equal	Right	Equal	Equal	Right
121	Left	Left	Equal	Right	Right	Right	Equal	Right
122	Left	Left	Left	Equal	Equal	Equal	Equal	Equal
123	Left	Equal	Left	Right	Right	Right	Left	Equal
124	Left	Left	Right	Right	Right	Right	Equal	Left
125	Left	Equal	Left	Right	Right	Right	Left	Left