THE EFFECT OF COMPETITION SPECIFIC AUDITORY STIMULUS DIVE TRAINING ON SWIMMING START REACTION TIME: A RANDOMISED CONTROLLED TRIAL

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ABSTRACT

A competitive swimming start shares similar auditory starting stimuli with that of an athletics track start, yet despite there being some research on reaction time (RT) training in athletics sprinting, there is a paucity of knowledge regarding RT training for swimming starts. The purpose of this study was to examine the effect of competition specific auditory stimuli, compared to dive training without auditory stimuli, on the RTs of male sub-elitc adolescent swimmers. It was hypothesised that auditory stimulus dive training can significantly improve swimming start RT and potentially bridge the previously found performance gap in RTs between sub-elite and elite level swimmers. Ten NSW state level swimmers (14.0 ± 1.4 years) were randomly allocated into two four week dive training programs; dive training without auditory stimulus (Cohort 1: C1, n=5) or competition specific auditory stimulus dive training (C2, n=5). Swimmers’ RT (≥ 0.100s), block time (BT) and ‘time to 15m’ were measured pre- and post-intervention using an instrumented starting block, with a custom made force measurement device (1000Hz), and a high speed camera (96Hz). Pre- and post-intervention results from all three parameters were compared to those of a group of six male elite level (Australian open national level) swimmers (C3) (19.8 ± 1.0 years). A significant Time by Group interaction (p = .005) indicated that competition specific auditory stimulus dive training resulted in faster participant RTs in response to the auditory ‘go’ signal when compared with regular dive training. C2 had significantly faster post- than pre-intervention RT results (p = .028), whereby the cohort mean RT reduced by 0.012s and the mean cohort effect size was of ‘large’ (d ≥ ± 0.8) magnitude (d = .99). C1 had a slower mean cohort RT from pre- to post-intervention, which approached statistical significance (p = .098) and a ‘large’ mean cohort effect size (d = .74). There were no significant differences in C3’s pre-intervention RTs and C2’s pre-intervention (p = .377) or post-intervention RTs (p = .766). However, C3 had significantly faster BTs than C1 (p = .016) and C2 (p = .048) pre-intervention. Neither of the two dive training interventions revealed statistically significant changes to BT or ‘time to 15m’ post-intervention. The present study demonstrates that
auditory stimulus training can improve the RT of swimmers to the starting signal. However, this contribution to performance is small relative to the other components of ‘time to 15m’; BT, flight time and underwater time. Further research is required to investigate the effect of auditory stimulus training with elite level swimmers, especially those competing in short distance events, and other sports such as athletics.

**Keywords:** reaction time, auditory stimulus, motor control and learning, swimming
Table of Contents

PRELIMINARY MATERIALS................................................................................................................... 6
TABLES LIST ........................................................................................................................................ 6
  Literature Review............................................................................................................................... 6
  Methodology...................................................................................................................................... 6
  Results............................................................................................................................................... 6
FIGURES LIST ...................................................................................................................................... 7
  Literature Review............................................................................................................................... 7
  Methodology...................................................................................................................................... 7
RESEARCH .......................................................................................................................................... 8
CHAPTER 1: INTRODUCTION ............................................................................................................. 8
CHAPTER 2: LITERATURE REVIEW .................................................................................................... 10
  2.1 Auditory stimuli and reaction time ............................................................................................ 10
    2.1.1 Simple auditory reaction time in sport ................................................................................. 10
    2.1.2 Reaction time: Sensorimotor neural pathways .................................................................. 12
    2.1.3 Auditory stimuli and reaction time summary ..................................................................... 13
  2.2 Sub-elite versus elite level athletes ............................................................................................. 13
  2.3 Swimming start performance ...................................................................................................... 14
    2.3.1 Swimming start phases ....................................................................................................... 15
    2.3.2 Swimming start training interventions .............................................................................. 17
    2.3.3 Swimming warm-up interventions ..................................................................................... 22
  2.4 Methodology in swimming start research ............................................................................... 23
    2.4.1 Sample and participants ..................................................................................................... 23
    2.4.2 Research design .................................................................................................................. 24
    2.4.3 Data collection methodology: Analysis of reaction time and block time ......................... 26
    2.4.4 Data collection methodology: Force measurement device ............................................... 28
    2.4.5 Data collection methodology: Questionnaire instrument .................................................. 29
    2.4.6 Methodology in swimming start research summary ............................................................ 30
  2.5 Literature review summary ......................................................................................................... 30
CHAPTER 3: METHODOLOGY .......................................................................................................... 31
  3.1 Participants .................................................................................................................................. 31
  3.2 Research design .......................................................................................................................... 32
  3.3 Testing procedures ....................................................................................................................... 33
  3.4 Swimming start variables .......................................................................................................... 35
3.5 Data collection ........................................................................................................... 35
  3.5.1 Instrument: Force measurement device ......................................................... 36
  3.5.2 Instrument: High speed camera ........................................................................ 40
  3.5.3 Instrument: Questionnaire .............................................................................. 41
3.6 Data analysis ............................................................................................................. 43
  3.6.1 Data analysis: Force measurement device ....................................................... 43
  3.6.2 Data analysis: High speed camera .................................................................... 47
  3.6.3 Data analysis: Questionnaire ............................................................................ 48
3.7 Statistical analysis .................................................................................................... 48

CHAPTER 4: RESULTS ...................................................................................................... 49
  4.1 Participant compliance ......................................................................................... 49
  4.2 Swimming start data: Inclusion and exclusion .................................................... 50
  4.3 Swimming start interventions: Summary of results ............................................ 50
  4.4 The effect of competition specific auditory stimulus training on swimming start reaction time ........................................................................................................... 52
  4.5 The effect of regular dive training and regular dive training with competition specific auditory stimulus on swimming start performance .................................................. 53
    4.5.1 Block time analysis ....................................................................................... 53
    4.5.2 ‘Time to 15m’ analysis .................................................................................. 53
  4.6 Reaction times and block times of sub-elite and elite level swimmers ............... 54
  4.7 Participant perceptions of swimming start training interventions ..................... 54

CHAPTER 5: DISCUSSION ................................................................................................. 56

CHAPTER 6: CONCLUSIONS AND IMPLICATIONS ....................................................... 64
  6.1 Conclusions .......................................................................................................... 64
  6.2 Limitations and future directions ........................................................................ 65

REFERENCES ................................................................................................................. 68

APPENDICES .................................................................................................................. 77
  Appendix 1: Participant information sheets and consent forms ............................... 77
  Appendix 2: Ethics approval letter ............................................................................ 91
  Appendix 3: Swimming start data collection ............................................................ 93
PRELIMINARY MATERIALS

TABLES LIST

Literature review

**Table 1:** Participant samples evident in swimming start intervention research (previously cited in ‘swimming start training interventions’ 2.3.2)

**Table 2:** Swimming start data collection methodology, assessing BT and/or RT (previously cited in ‘Swimming start performance’ 2.3)

Methodology

**Table 3.** Outline of implemented dive training interventions across two cohorts of sub-elite adolescent swimmers

**Table 4:** Questionnaire (cohort 2): Perceptions of competition specific auditory stimulus dive training

**Table 5:** Determining the time point of muscular activation during a swimming start

**Table 6:** Summary of the analysis criteria for each significant time point during the ‘on-block’ phase

Results

**Table 7:** Participant attendance and number of dives completed

**Table 8:** Summary of the effect of swimming start interventions on RT, BT and ‘time to 15m’

**Table 9:** Questionnaire results: Participant perceptions of swimming start training interventions
FIGURES LIST

Literature review

Figure 1: On-block phase (Squire, 2012)
Figure 2: In-flight phase (Squire, 2012)
Figure 3: Underwater phase (Macnicol, 2012)
Figure 4: Free swimming phase (Bello, 2012)

Methodology

Figure 5: Piezo cable image (Measurement Specialities, 2015)
Figure 6: Internal structure of a piezo cable (Images, 2015)
Figure 7: Omega OSB-11 starting block (Swiss Timing, 2009)
Figure 8: Omega OSB-11 starting block with force measurement device attached
Figure 9: Data collection setup
Figure 10: Speaker, electronic horn and wireless microphone
Figure 11: Diagram of swimming start testing data collection setup
Figure 12: Change in force production during a swimming start
Figure 13: Change in audio data in response to the auditory ‘go’ signal
CHAPTER 1: INTRODUCTION

Swimming at a competitive international level was first introduced to the Olympic Games in 1896, with the 1956 Olympic Games being the first year that all four swimming strokes were represented. While there has been a growing volume of research related to improving swimming performance, research aimed at developing training methods to improve swimming start performance remains sparse. Research has focussed mainly on elite level athletes, with less attention given to investigating performance improvement in competitive adolescent swimmers. Competitive adolescent swimmers are the next generation of elite level swimmers and therefore would benefit from tailored, evidence-based training interventions aimed at improving swimming start and overall race performance.

Start times to 15m have been found to vary from 0.8% to 26.1% of the overall race time, depending on the event (Cossor & Mason, 2001) with the percentage contribution decreasing with increasing race distance (Hay, 1986). While it is known that improvements in swimming start technique can reduce total time of an event by at least 0.1s (Maglischo, 1999 cited in Ruschel, Araujo, Pereira, & Roesler, 2007) there is a scarcity of research assessing the effect of dive training interventions on the reaction time (RT) of competitive swimmers. Scrutiny of daily swimming programs reveals that the majority of current competitive swimmers do not complete habitual dive training with the same auditory stimuli used to commence a swimming race. Task specific training has been shown to improve participant RTs when re-exposed to the same stimulus (Nuri, Shadmehr, Ghotbi, & Attarbashi Moghadam, 2013; Gavkare, Nanaware, & Surdi, 2013; De Souza, Yehia, Sato, & Callan, 2013; Tong, Melara, & Rao, 2009). While RT training interventions have been used effectively in non-sporting literature (Madanmohan et al., 1992), there is a paucity of research investigating the effect
of using task specific training, with the aim of improving athletes’ RTs, in sporting codes involving auditory stimuli.

Reaction time is a small component of the total time spent during the on-block phase of a swimming start. It may be hypothesized that RT improvements would result in an earlier application of force by the swimmers and reduce BT. Since the introduction of the Omega OSB-11 starting blocks (Swiss Timing, 2009) into international competitive swimming, swimmers have been able to produce faster BTs without the trade-off of reduced horizontal take-off velocity (Honda, Sinclair, Mason, & Pease, 2010; Slawson, Conway, Cosser, Chakravorti, & West, 2013). Therefore, improvements in participant BTs have the potential to improve overall swimming start performance (‘time to 15m’).

Experienced competitive swimmers spend less time between the start signal and applying force to the block than less experienced swimmers (Vantorre, Chollet, & Seifert, 2014). However, there exists a gap in the research surrounding the development of effective swimming start training methods for swimmers who have the potential to progress to a higher level of competitive swimming. The purpose of this study was to examine the effect of competition specific auditory stimuli, compared to dive training without auditory stimuli, on the RTs of male sub-elite (state level) adolescent swimmers. It was hypothesised that auditory stimulus dive training can significantly improve swimming start RTs and potentially bridge the previously found performance gap in RTs between sub-elite and elite level swimmers.
CHAPTER 2: LITERATURE REVIEW

2.1 Auditory stimuli and reaction time

Tripp (1965) stated that practice of a skill reduces decision time (recognition of an auditory ‘go’ stimulus) and thus enables the correct decision to be made more efficiently. Furthermore, if an act is practised enough a conditioned reflex may develop, such as an athletics track sprinter becoming conditioned to the starting auditory stimulus. Competitive swimming and track running involve a speaker and an auditory ‘go’ signal to commence a race. Reaction time is considered to be the time between the stimulus being presented and the initiation of muscular activation (Johnson & Nelson, 1988). It is evident through research that RTs during sport are faster among elite level athletes than sub-elite trained athletes (Vantorre et al., 2014; Slawinski et al., 2010). Also, task specific training has been shown to improve RT in various sports and training tasks (refer to 2.1.1). Furthermore, training for specific frequencies of sound with an associated behavioural task has shown neurological changes to sensorimotor neurological pathways associated with simple auditory RT within subjects, when they are re-exposed to the same stimulus (refer to 2.1.2).

2.1.1 Simple auditory reaction time in sport

Simple auditory RT in swimming is dependent on several factors; auditory stimulus (‘go’ signal) reaching the sensory organ (ear), conversion of the stimulus to a neural signal, neural transmissions and processing and then muscular activation (Pain & Hibbs, 2007). The associated processing time for each of these components contributes to the overall RT during a swimming start. The simple auditory RT is thought to be rarely less than 100ms and is known to be one of the fastest forms of RT (Thompson et al., 1992). It is for this reason that the International Association of Athletics Federations (IAAF) has a false start criterion during athletics of 100ms, working under the
assumption that athletes who have reacted in under 100ms have anticipated the starting signal (IAAF, 2016, “100 Metres”, para. 1).

In athletics the fastest likely pre-motor (prior to muscular activation) time, based on the involuntary startle reflex response and inclusive of the time for the start signal to travel to the athlete, is 63ms (Pain & Hibbs, 2007). This value (63ms) is derived from the processing times associated with the signal reaching the brainstem from the ear (10ms) and then from the brain stem to the spinal cord and subsequent innervation of muscles (50ms) (Kemp, Coppeé, & Robinson, 1937). While 63ms is theoretically the lowest likely pre-motor time for the involuntary startle reflex, RT is a voluntary response to the auditory stimulus, requiring further neural processing and resulting in longer RTs. Analysis of 100m track sprinters at the Athens Olympic Games (2004) revealed an average RT of male (n=76) and female sprinters (n=50) of 0.164s and 0.184s respectively (Delalija & Babić, 2008). Prior to the introduction of the OSB-11 starting blocks, swimmers using the track start technique have been found to exhibit RTs of 0.23s (Blanksby, Nicholson, & Elliott, 2002) and as low as 0.17s (Benjanuvatra, Lyttle, Blanksby, & Larkin, 2004).

Sensory-cognitive skills of athletes have been found to be greater in their specific sport domain. Auditory RT and anticipatory skill were tested in a group of athletes consisting of eleven track sprinters and eleven volleyball players (Nuri et al., 2013). Sprinters were found to have faster auditory RTs whilst volleyball players showed superior anticipatory skill. This was further supported by Gavkare, Nanaware and Surdi (2013) who concluded that auditory, visual, and whole body RTs were significantly less in athletes (n=50) than healthy participants of the same age (n=50). Findings from the literature reveal that elite athletes across different sporting codes exhibit faster RTs in their specific sport when compared with other tasks. Therefore, it would be expected that task specific training, such as simulated competition swimming starts, could improve RT in the given task. It has
been suggested that improvements in task specific RTs can be attributable to changes in sensorimotor neural pathways associated with a simple auditory RT.

2.1.2 Reaction time: Sensorimotor neural pathways

Neuronal functional specificity refers to favourable alterations to the previously discussed factors of simple auditory RT, resulting in faster processing times to a specific stimulus when the subject is re-exposed to it (De Souza et al., 2013). Neuronal functional specificity to sensory stimulation has been shown to be alterable and specific to experience. De Souza et al. (2013) examined auditory frequency discrimination, using functional magnetic resonance imaging (fMRI) and electroencephalography (EEG), in eleven subjects (ten males) with a mean age of 24 years. Functional magnetic resonance imaging measures brain activity by detecting changes in blood flow to specific regions of the brain, whilst EEG devices record electrical activity in the brain through the use of surface electrodes. Improvements in task performance by the participants were associated with plastic changes in the sensory cortex and superior areas that are gated by selective attention. In another neuroscience study, auditory tone discrimination and an associated behavioural response was analysed by a device that measured the magnitude of auditory event-related potentials (Tong et al., 2009). This refers to electrical impulses within the brain in response to the stimulus. The researchers used a specific waveform component (‘P2’) of electrical impulses within the brain as an outcome measure for the study. Participants performed both passive (listening) and active (detecting) ‘oddball’ tasks in pre-training and post-training tests. ‘Oddball’ tasks have been used throughout neuroscience research and involve presenting participants with sequences of repetitive auditory/visual stimuli which are then interrupted by a deviant stimulus. The participants are required to respond to the target stimulus which occurs rarely amongst a series of more common stimuli. Tong and colleagues (2009) found that the ‘oddball’ training tasks improved both perceptual
sensitivity and RTs, which correlated with enhancement of the measured waveform component. Thus, repeated auditory stimuli discrimination training was associated with faster participant RTs.

2.1.3 Auditory stimuli and reaction time summary

Task specific training has been shown to improve participant RTs when they are re-exposed to the same stimulus (Nuri et al., 2013; Gavkare et al., 2013; De Souza et al., 2013; Tong et al., 2009). This improvement in RT can be attributed to neuronal functional specificity which involves faster processing times in the sensorimotor pathways associated with a simple auditory RT (De Souza et al., 2013). Sub-elite (competitive adolescent) swimmers have been shown to have slower swimming start RTs than elite level swimmers (Vantorre et al., 2014). Consequently, the concept of neuronal functional specificity, to an auditory ‘go’ signal, has implications in competitive swimming through the use of auditory RT training. Re-exposing sub-elite swimmers who are on the cusp of progressing into elite level swimming to competition specific auditory stimuli during regular dive training, has the potential to reduce RT and translate to improvements in overall swimming start performance.

2.2 Sub-elite versus elite level athletes

Sub-elite adolescent swimmers are deemed as ‘sub-elite’ as they have slower race times than elite level swimmers across the same event. Noticeably, this performance gap also holds for swimming start performance variables such as RT and the time spent on the diving block (‘block time’: BT). A systematic review conducted by Vantorre, Chollet and Seifert (2014) revealed that experienced competitive swimmers spent less time between the start signal and applying force to the block than less experienced swimmers. Experienced swimmers have a greater accumulation of time spent at a competitive level, which is thought to produce faster RTs through more directed concentration on
the starting auditory stimulus and less nervous system processing whilst on the block (Maglischo, 1982).

Given that track starts in athletics are similar to swimming track starts with regard to body positioning, kinematics and competition auditory stimuli, research in athletics may also provide insight to competitive swimming starts. In a study comparing kinematic, kinetic and dynamic parameters of six elite and six well-trained runners during a block start, the rate of force development and impulse were significantly greater in elite sprinters than sub-elite sprinters (Slawinski et al., 2010). The studies by Vantorre et al. (2014) and Slawinski et al. (2010) highlighted that elite athletes are highly trained and are more efficient in their specific starting technique, resulting in faster BTs and greater performance outcomes than sub-elite athletes. The performance gap in BT could also be attributed to faster athlete RTs, as RT is a small component of the overall time spent on a starting block in both swimming and athletics. Consequently, it is worth exploring whether competition specific auditory stimulus dive training can be used to effectively improve RTs of sub-elite adolescent swimmers towards that of elite level swimmers.

2.3 Swimming start performance

In line with the underwater phase limit implemented by the world swimming governing body, FINA, the ‘swimming start’ is considered to be the first 15m of a race, where the swimmer must break the surface of the water before 15m and commence swimming (Cossor & Mason, 2001). Of the ‘time to 15m’, the swimming start is comprised of three overall components; BT, flight time and water time (Blanksby et al., 2002; Guimaraes & Hay, 1985; Maglischo, 2003; Schnabel & Kuchler, 1998). Within these components of the swimming start, researchers have aimed to identify the key characteristics of dive technique that have a direct relationship with overall swimming start performance (refer to 2.3.1). These studies primarily involve the outcome measure BT as part of their analysis (refer to
2.3.1), while there is a paucity of studies addressing swimming start performance through the analysis of RT. The evidence suggests that with practice, swimmers learn an effective combination of minimising time spent on the block and maximising take-off velocity (Guimaraes & Hay, 1985; Vantorre, Seifert, Fernandes, Boas, & Chollet, 2010). Additionally, as improvements in swimming start technique can reduce the event’s total time by at least 0.1s (Maglischo, 1999 cited in Ruschel et al., 2007), researchers have assessed the effectiveness of training (refer to 2.3.2) and warm-up (refer to 2.3.3) interventions on swimming start performance.

2.3.1 Swimming start phases

Key parameters of a competitive swimming start were analysed systematically by Tor, Pease and Ball (2014) to determine their relationship to start performance. This involved retrospective dive testing data taken from a group of elite level swimmers (n=52) using the Omega OSB11 starting blocks, ‘Wetplate Analysis System’ and the ‘Swimtrak Timing System’ (Mason, Mackintosh, & Pease, 2012). A criterion for inclusion was that the participants had been selected in at least one senior Australian national swimming team (Olympics and/or World Championships) and were excluded if their dive testing was performed with the now illegal swimsuits. The swimming start was characterised by the time between the starting signal and the swimmer reaching the 15m mark. Analysis of the data revealed the mean percentage and time spent within each specific phase of a swimming start; ‘on-block’ 11% (0.74s), ‘in-flight’ 5% (0.30s), ‘underwater’ 56% (3.69s) and ‘free swimming’ 28% (1.81s). Block time or the ‘on-block’ phase (Figure 1) has been defined as the time between the starting signal and the last moment of contact with the starting block (Blanksby et al., 2002). The ‘in-flight phase’ (Figure 2) is denoted as time between the last moment of contact with the block and the swimmers initial contact of the water. The ‘underwater phase’ (Figure 3) is then made up of a glide component and followed closely by dolphin kicking (freestyle and butterfly). Finally, the ‘free
swimming’ phase (Figure 4) is considered as the time between the swimmer breaking the surface of the water and their head reaching the 15m mark.

**Figure 1:** On-block phase (Squire, 2012)  
**Figure 2:** In-flight phase (Squire, 2012)  
**Figure 3:** Underwater phase (Macnicol, 2012)  
**Figure 4:** Free swimming phase (Bello, 2012)

Block time quantifies the combined reaction and movement times of swimmers during a swimming start. A number of studies have quantified average BTs amongst participant groups consisting of sub-elite (‘state level’) and elite (‘national’ and ‘international level’) level swimmers. The study by Tor, Pease and Ball (2014) found elite level male swimmers had an average BT of 0.72s and females, 0.77s. Ruschel, Araujo, Pereira and Roesler (2007) found an average BT of 0.85s within a group of four state and national level Brazilian swimmers. Benjanuvatra, Lyttle, Blanksby and Larkin (2004) found an average BT during grab and track starts of 0.94s and 0.89s respectively of nine male and seven female national and international level swimmers. Similarly, research carried out in Spain using a group of elite level swimmers (n=17) reported a subject average BT of 0.850s (Arellano,
Pardillo, De La Fuente, & Garcia, 2002). Finally, at the Sydney Olympic Games (2000), Cossor and Mason (2001) of the Australian Institute of Sport analysed swimming start performances of semi-finalists and finalists. Analysis of the 100m butterfly event revealed that swimmers who were slower to leave the blocks recorded slower 15m start times.

It is evident that average BTs in both sub-elite and elite level swimmers approaches one second (Ruschel et al., 2007; Benjanuvatra et al., 2004; Arellano et al., 2002), which amounts to a significant percentage of overall race time in sprint races. Furthermore, research has shown that reductions in BT translate to improvements in overall start performance, regardless of the event (Garcia-Hermoso et al., 2013; Vantorre et al., 2010). Consequently, the integration of auditory RT training methods, coupled with regular dive training, may have the potential to improve BT and overall swimming start performance.

### 2.3.2 Swimming start training interventions

Research has revealed that elite level swimmers exhibit an effective combination of minimizing time spent on the block and maximising their take-off velocity during a swimming start (Guimaraes & Hay, 1985; Vantorre et al., 2010). As a result, swimming training interventions have been implemented to assess their effect on BT and swimming start performance, with the goal of informing training techniques. Types of swimming start training interventions include: jump training (‘plyometrics’), resistance training and regular dive training.

Plyometric training focuses on moving from muscle extension to contraction in a rapid manner (Chu, 1998) and is seen as an effective form of exercise to induce functional muscular changes (Masamoto, Larson, & Gates, 2003). Improvements in swimming start performance through the use of plyometric training have been brought about by increased take-off velocity, resulting in faster 15m start times.
Improvements in take-off velocity are attributable to changes in torque of the lower limbs and greater horizontal force being applied through the block during a swimming start. Investigation of changes in torque of the lower limb joints as a result of plyometric training and its translation to the kinetics and kinematics of a swimming start was conducted on a group of ten experienced swimmers (seven male: 22 ± 1.4 years, three female: 21.3 ± 7.6 years) (Rebutini, Pereira, Bohrer, Ugrinowitsch, & Rodacki, 2014). The nine week plyometric training program significantly increased hip and knee torque as well as horizontal force, impulse and horizontal take-off velocity. Bishop, Smith, Smith and Rigby (2009) examined the effect of a plyometric training intervention on swimming starts, using a performance based outcome measure of ‘time to 5.5m’. The study involved a group of adolescent swimmers (n=11, 13.1 ± 1.4 years) who performed two weekly one hour plyometric specific sessions, over eight weeks. The intervention group showed significantly greater improvement in start performance than the control group (n=11, 12.6 ± 1.9 years), reducing time to 5.5m by 0.59s in the intervention group, compared with a reduction of 0.21s in the control (p < .01). Furthermore, a four week combined training program involving plyometric, swimming start and visual and auditory components was implemented on a treatment group of eight male national level sprint swimmers (17.5 ± 0.9 years) (Lepretre, Kazarine, Puel, Chollet, & Fernandes, 2014). This cohort study resulted in improved 15m start times of the participants by approximately 1.0%.

The effect of land plyometric training versus aquatic plyometric training on swimming start performance was investigated by Hassannezhad, Bahadoran, Ramezanpour and Attarzade (2012). The study involved a six week training period (three sessions per week) using lifesavers who were randomly allocated into three cohorts; land training (n=7), aquatic training (n=7) and control (n=7). Training sessions were 45 to 60min in length and consisted of depth, star, rocket and squat jumps, either on land or in an aquatic setting. The results revealed insignificant changes in BT from pre- to post-intervention for both land and aquatic plyometric training when compared with the habitual training group. Furthermore, no significant differences in start performance were found when
comparing land plyometric training and aquatic plyometric training. The ineffectiveness of these interventions on start performance may have been attributable to the fact that the lifesavers were not skilled in the technique of competitive swimming dives prior to the intervention period.

Throughout the literature it has been shown that plyometric land training with competitive swimmers improves start performance through the increase in take-off velocity (Rebutini et al., 2014), and the subsequent translation to improvements in 5.5m (Bishop et al., 2009) and 15m (Lepretre et al., 2014) start times. These improvements may also be due to plyometric training mimicking a swimming start with an explosive push off and the demonstration of similar kinematic properties. However, plyometric training literature does not account for changes in RT and BT when considering improved swimming start times. Therefore, it is worth exploring how changes in RT and BT in response to training interventions correlate to overall swimming start performance.

Lower limb resistance training programs are also evident throughout the literature and have shown to improve swimming start performance outcomes. Similar to plyometric training, physiological changes in swimmers as a result of resistance training interventions have also improved take-off velocity and resulted in faster performance outcomes. These improvements are evident in a study involving German international swimmers (n=7) which comprised of a four week lower limb strength training program consisting of three weekly training sessions (Hohmann, Fehr, Reuss, Straub, & Kieser, 2010). Swimming start performance was measured pre-intervention, post-intervention, and four weeks post-intervention (retention time point). Maximum and explosive strength parameters (countermovement jump and squat jump) of the lower limb improved, as well as time to 7.5m (Pre-intervention = 2.70 ± 0.28s vs Retention time point = 2.63 ± 0.28s). In addition to this, Breed and Young (2002) randomly allocated a cohort of non-competitive (athletes from different sport codes other than swimming) female swimmers into a resistance training group (n=12) and a control group (n=11). The resistance training group undertook three training sessions a week for nine weeks. Dive
start testing was performed by both groups, pre-intervention and post-intervention, by performing three diving techniques (grab, track and swing). Analysis of the results revealed significant changes in take-off velocity, take-off angle and horizontal impulse in the track start technique only, when comparing the resistance group with the control group. However, while results revealed that resistance training improved jumping ability and increased vertical force components across all three starting techniques, Breed and Young (2002) suggested the need to practise swimming dives to translate improvements in neuromuscular properties to performance gains. The suggestion supports the need to practice the diving technique during a resistance training regime to augment the skill and control mechanisms of the neuromuscular system (Bobbert & Van Soest, 1994). This concept informs the use of auditory RT training during regular diving practice to translate potential neuromuscular changes to improvements in swimming start performance.

While resistance and plyometric training interventions have improved swimming start performance, regular dive training and changes in diving technique have also been implemented successfully. Regular dive training has been shown to result in faster times across all phases of a swimming start. Blanksby et al. (2002) investigated the effect of dive start practice in grab, track and handle swimming starts, on swimming start performance. Twelve elite level swimmers completed fifteen starts (five grab and ten track starts) between two and four sessions per week until they accumulated 14 +/- 2 practice sessions. Participants improved 10m, reaction, movement, block and flight times irrespective of the start technique. Mean RT improved from 0.22s to 0.19s irrespective of the starting technique when analysed pre and post-intervention and was suggested to have occurred as a result of swimmers having improved concentration and reduced levels of anxiety whilst on the block. Block time results also improved pre- to post-intervention from 0.86s to 0.80s, inferring that regular dive training may induce similar physiological changes to that of plyometric training due to the act of repeated explosive swimming dives.
Alterations in diving technique through the application of muscular pre-tension (static muscular contraction) whilst performing a swimming start has shown to result in faster BTs. Lee, Huang, Lin and Lee (2002) investigated muscular pre-tension in a group of eight well trained swimmers (20.0 ± 2.5 years) to analyse its effect on swimming start performance. This involved the analysis and comparison of three protocols; stretch-shortening cycle, purely concentric with no pre-tension and purely concentric with pre-tension. The stretch-shortening cycle involved a countermovement where the swimmer would squat after the starting signal and then project themselves forwards. The protocol involving no muscular pre-tension had participants responding to the starting signal and diving with concentric contraction of their lower limb. In contrast, muscular pre-tension was achieved in the third protocol by instructing participants to apply force on the block with their legs prior to the starting signal. There were significant differences between the three protocols with regard to BT, in which pre-tension recorded the fastest mean time, followed by no pre-tension and the stretch-shortening cycle (pre-tension = 0.77 ± 0.07 s, no pre-tension = 0.82 ± 0.06 s and stretch-shortening cycle = 0.91 ± 0.07 s).

Based on the literature discussed, training interventions can improve overall swimming start performance (15m start times) by increasing torque of the lower limbs and horizontal force, resulting in increased take-off velocity and reductions in BT. These improvements have been achieved through land plyometric training (Rebutini et al., 2014; Bishop et al., 2009; Lepretre, 2014), resistance training (Hohmann et al., 2010; Breed & Young, 2002) and dive training (Blanksby et al., 2002; Lee et al., 2002). Start times to 15m have been found to vary from 0.8% to 26.1% of the overall race time, depending on the event (Cossor & Mason, 2001) with the percentage contribution decreasing with increasing race distance (Hay, 1986). Improvements in swimming start performance by training interventions could translate to substantial improvements in race times, especially during sprint races.
The study conducted by Lepretre et al. (2014) included auditory components within the plyometric and swimming start training program, but the cohort study design made it difficult to conclude the extent of the effect of auditory components on swimming start RT. Thus, a randomised controlled trial intervention study analysing RT, similar to the study carried out by Blanksby et al. (2002), with competition specific auditory stimulus dive training, would assist in filling the gap in the literature regarding swimming start RT training techniques.

2.3.3 Swimming warm-up interventions

Competitive swimmers undertake a specifically designed warm-up program prior to competition. A swimming warm-up involves physical activity before the main event with the intention of improving swimming performance (Bobo, 1999). As previously mentioned, changes in torque of the lower limb joints and BT has the potential to affect swimming start performance. Cuenca-Fernández, López-Contreras and Arellano (2015) investigated the effect of warm-up techniques on BT and angular velocity of knee extension during a swimming start. The study involved trained swimmers (n=14) and used a previously trialed standardised warm-up with the addition of two protocols of post-activation potentiation. The first protocol involved three lunges at 85% of one repetition maximum and the second involved four repetitions on the flywheel device ‘YoYo’ squat. The mean values obtained for BT and angular velocity of knee extension were both better after the ‘YoYo’ squat protocol compared to the other two protocols (lunge protocol and control).

Balilionis et al. (2012) trialled three types of warm-ups on a group of sixteen competitive swimmers (eight male: 19.9 ± 0.6years, eight female: 19.8 ± 0.7years) to assess their effect on swimming start performance and RT. A regular warm-up, resulted in better 50yard freestyle times than a shortened warm-up (50yard freestyle at 40% maximal effort and 50yard at 90%) and no warm-up. However, no significant differences in RT were recorded across the three groups. Consequently, altering warm-
ups of swimmers prior to competition has the potential to alter BT and swimming start performance. Therefore, a controlled standardised warm-up must be considered when assessing the effectiveness of training interventions on swimming start performance to limit any confounding factors.

2.4 Methodology in swimming start research

Investigations into the effect of training interventions on swimming start performance are important in informing the development of research based training programs that can be integrated as part of competitive swimmers’ habitual training. There is a paucity of studies involving controlled study design swimming start training interventions. Swimming start training intervention research includes a variety of analysis techniques that have been used to obtain quantitative data such as BT, while research analysing RTs of competitive swimmers remains sparse.

2.4.1 Sample and participants

A variety of participant groups are evident in swimming start intervention studies. However, the main cohorts have been elite level swimmers, as summarised in ‘Table 1’. In these studies (Hohmann et al., 2010; Lepretre, 2014; Rebutini et al., 2014) national level was usually a minimum required skill level and swimmers had a mean age over 20 years (Table 1). Excluding the study by Bishop et al. (2009), studies of competitive swimming used small sample groups ranging from seven to twelve participants. Bishop et al. (2009) focussed purely on sub-elite adolescent swimmers, with a mean age of 12.9 years. The remaining two studies (Breed & Young, 2002; Hassannezhad et al., 2012) involved participants who were not well trained in the skill of diving and thus the findings did not relate to improving start performance among competitive swimmers. Three of the studies (Blanksby et al., 2002; Hohmann et al., 2010; Rebutini et al., 2014) listed in ‘Table 1’ analysed the effect of swimming start interventions with a sample group consisting of both males and females, resulting in
potential confounding of their final results due to differences in gender. The swimming start performance gap between sub-elitist and elite level athletes (Vantorre et al., 2014; Slawinski et al., 2010) and the scarcity of research related to improving sub-elitist adolescent swimmers’ performances, highlights the need for further research involving adolescent swimmers. While training interventions can improve start performance in elitist level swimmers, the extent of performance improvement among sub-elitist adolescent swimmers is an important focus area for the development of the new wave of elite level swimmers.

Table 1. Participant samples evident in swimming start intervention research (previously cited in ‘Swimming start training interventions’ 2.3.2)

<table>
<thead>
<tr>
<th>Primary Author, Year</th>
<th>Participants (n)</th>
<th>Male (n):Female (n)</th>
<th>Mean age (years)</th>
<th>Skill level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bishop, 2009</td>
<td>22</td>
<td>NR</td>
<td>12.85</td>
<td>Sub-elite*</td>
</tr>
<tr>
<td>Blanksby, 2002</td>
<td>12</td>
<td>5:7</td>
<td>17.70</td>
<td>NR**</td>
</tr>
<tr>
<td>Breed, 2002</td>
<td>23</td>
<td>0:23</td>
<td>19.90</td>
<td>Un-trained***</td>
</tr>
<tr>
<td>Hassannezhad, 2012</td>
<td>21</td>
<td>21:0</td>
<td>24.40</td>
<td>Un-trained</td>
</tr>
<tr>
<td>Hohmann, 2010</td>
<td>7</td>
<td>5:2</td>
<td>22.14</td>
<td>National</td>
</tr>
<tr>
<td>Lepretre, 2014</td>
<td>8</td>
<td>8:0</td>
<td>17.50</td>
<td>National</td>
</tr>
<tr>
<td>Reboutini, 2014</td>
<td>10</td>
<td>7:3</td>
<td>21.65</td>
<td>National</td>
</tr>
</tbody>
</table>

*Minimum of 8 hours of aquatic training per week
**Not recorded
***Athletes from a range of sporting disciplines other than swimming

2.4.2 Research design

When considering the research design of the training intervention studies in ‘Table 1’, participant groups were obtained through a convenience sample approach. Once participants have volunteered and consent has been gained, these studies exhibit two distinct forms of study design. Under these two designs, the intervention period in each study varies in length and frequency of training sessions. The first study design comprises an intervention period in the absence of a control group, with a pre- and post-intervention testing protocol. Hohmann et al. (2010) adopted this approach,
implementing a strength training intervention program three days a week, for four weeks. Similarly, Lepretre et al. (2014) carried out a four week cohort study on a treatment group, who underwent plyometric and swimming start training coupled with visual and auditory components. Rebutini et al. (2014) opted for a longer training period of nine weeks and also performed ‘before and after’ swimming start performance tests. It is important to note that while performance improvements were shown across all three training interventions, the true correlation between the intervention and swimming start performance is difficult to determine due to the unknown effect of habitual training during the intervention period. Habitual training may have contributed to a proportion of the participants’ final improvement. Consequently, studies involving a ‘randomised controlled trial’ (RCT) study design have the advantage of showing a clearer causality between an intervention and performance outcomes.

The RCT approach involves taking the participants and randomly allocating them to intervention group(s) and a control group. A pre- and post-intervention test is then performed in all groups to analyse and compare any potential effect of the intervention. Bishop et al. (2009) randomly allocated participants to a habitual training group and a plyometric training group. The plyometric training group participated in two one hour sessions a week, for eight weeks, in addition to their habitual training (which was continued by the control group). Blanksby et al. (2002) randomly allocated participants to one of two treatment groups (track or handle swimming starts) or a control group (grab start). All three groups performed two to four sessions per week until 12-16 sessions were accumulated. In the remaining two studies (Breed & Young, 2002; Hassannezhad et al., 2012) a RCT approach was adopted. However, as previously mentioned, these participants were not competitive swimmers. Based on the RCT study conducted by Blanksby et al. (2002) a swimming start training intervention study consisting of three sessions per week for four weeks would be a viable study design to assess changes in swimming start RT from pre- to post-intervention.
2.4.3 Data collection methodology: Analysis of reaction time and block time

Table 2. Swimming start data collection methodology, assessing BT and/or RT (previously cited in ‘Swimming start performance’ 2.3)

<table>
<thead>
<tr>
<th>Primary Author, Year</th>
<th>Assessed BT</th>
<th>Assessed RT</th>
<th>Video analysis</th>
<th>Force plate</th>
<th>Infrared</th>
<th>Reaction pad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arellano, 2002</td>
<td>✓</td>
<td>X</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Balilionis, 2012</td>
<td>X</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Benjanuvatra, 2004</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blanksby, 2002</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>X</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Cossor, 2001</td>
<td>✓</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Cuenca-Fernández, 2015</td>
<td>✓</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Hassannezhad, 2012</td>
<td>✓</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Hohmann, 2010</td>
<td>✓</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Lee, 2002</td>
<td>✓</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lepretre, 2014</td>
<td>X</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Mason, 2012</td>
<td>✓</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Ruschel, 2007</td>
<td>✓</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vantorre, 2010</td>
<td>✓</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Studies previously cited in ‘Swimming start performance’ (2.3) that had BT and/or RT as outcome measures were tabulated (Table 2) along with their associated data collection instrument(s). Of the studies listed in Table 2, approximately 85% used video analysis with one or multiple Panasonic, Sony or Canon cameras situated on pool deck and/or underwater. These cameras were used to assess BT, with a variety of recording frame rates; 30Hz (Ruschel et al., 2007), 50Hz (Vantorre et al., 2010), 120Hz (Lee et al., 2002), 200Hz (Blanksby et al., 2002; Hassannezhad et al., 2012) and 300Hz (Arellano et al., 2002; Cuenca-Fernández et al., 2015). For example, Ruschel et al. (2007) positioned one of four cameras to attain a lateral view of the starting block, which was linked to the timing system. The team was then able to analyse the time from the initial starting signal until the swimmer was no longer in contact with the block. Another setup involved the positioning of a light emitting diode that was linked to the starting buzzer in the background of starting block (Blanksby et al., 2002). As a result, the high speed camera would capture the initial flash, corresponding to the ‘go’
signal, and the swimmer leaving the block. Post-test analysis involved superimposing time codes over the video to calculate the time spent on the block by the participants. The use of cameras with slower recording frame rates (e.g. 30Hz and 50Hz) reduce the precision of the recorded BT as the true moment of last contact with the block may reside between two frames. As a result, there may be a discrepancy up to 0.02s, when using a framing rate of 50Hz. Studies listed in Table 2 that involve the use of video analysis to determine BT, measured and reported BT to a hundredth of a second. Therefore, the use of video analysis for determining BT is limited by the frame rate capabilities of the camera and highlights the need for a more precise instrument to effectively analyse BT. Furthermore, video analysis techniques are unable to precisely measure RT, as change in force application through the block by the swimmer can occur prior to visible movement of the lower limbs occurring.

Other than video analysis, force measurement devices were also used as a data collection technique to analyse outcome measures such as peak horizontal force, BT and RT. One setup involved mounting a ‘Kistler’ (https://www.kistler.com/au/en/) force plate on the starting block, which was linked to the timing system (Lee et al., 2002). In contrast to this setup, custom built instrumented starting blocks that adhere to the block specifications set out by the world swimming governing body (FINA), were also used. Benjanuvatra et al. (2004) developed an instrumented starting block that consisted of two force plates mounted side by side to assess both lower limbs separately. The instrumented starting block provided temporal and kinetic measures including peak force, average force, impulse (vertical and horizontal), RT, movement time, BT and velocity. Similarly, the Australian Institute of Sport (Canberra, ACT) uses an instrumented block and ‘Wetplate’ analysis system to obtain similar measures (Mason et al., 2012). An additional data collection technique involved the use of a reaction pad (Daktronics, Brookings, SD, USA), which was attached to the block and synchronised to the timing system to give RT values to the nearest one hundredth of a second (Balilionis et al. 2012). Reaction time has also been assessed through the use of infrared optical
measurement technology, ‘Microgate Optojump’, which determined the first instance of movement in response to the visual and/or auditory stimuli (Lepretre et al., 2014). While high speed cameras can operate with framing rates such as 300Hz (Arellano et al., 2002; Cuenca-Fernández et al., 2015) force data can be collected using force plates operating at 500Hz (Benjanuvatra et al., 2004) and 600Hz (Lee et al., 2002). Force measurement instruments are advantageous as they operate at high recording rates and are in direct contact with the swimmer. The maximum error of identifying an event in milliseconds using a sampling rate of 500Hz would be one millisecond. Therefore, force measurement instruments are the optimal form of data collection when analysing RT.

2.4.4 Data collection methodology: Force measurement device

‘Piezoelectric’ is a term that describes the production of electricity in dielectric crystals in response to mechanical stress (Holler, Skoog, & Crouch, 2007, p. 9). Piezoelectric sensors measure pressure, acceleration, temperature, strain or force, by producing an electrical charge proportional to changes in these variables. In RT sporting literature piezoelectric sensors are primarily seen through the use of force plates with integrated piezoelectric transducers. Willwacher, Herrmann, Heinrich and Brüggemann (2013) analysed the force production and RT of track sprinters (n=99) to deduce optimal kinetics of a track start. The setup involved custom built force platforms with ‘piezo type’ force transducers attached to the starting block. The output from the force platforms was then synced to the starting signal to quantify RT. A similar setup also assessing force production and RT in track sprinters was constructed by Pain and Hibbs (2007). The researchers integrated piezoelectric force transducers into the footplates of the starting block. Comparable RT starting setups using Kistler force plates (Kistler Group, Switzerland) are also seen in swimming literature (Lee et al., 2002; Mason et al., 2012). Kistler force plates have integrated piezoelectric transducers and can measure the precise onset of force production by a swimmer during a
swimming start. Consequently, piezoelectric instruments are the optimal device for the precise measurement of pre-motor time due to their high recording rates e.g. 2000 Hz (Pain & Hibbs, 2007).

2.4.5 Data collection methodology: Questionnaire instrument

Sheard and Golby (2006) quantified perceptions of swimming performance during training and competition, through the use of a questionnaire. The research involved the implementation of a seven-week psychological skills training program on a group of sub-elite adolescent swimmers (n=36). The training program consisted of goal setting, visualisation, relaxation, concentration and though stopping. Quantitative data were then collected by having participants complete seven ‘inventories’ that measured performance (swimming times collected at official swimming meets) and psychological attributes associated with improved performance: mental toughness, hardiness, self-esteem, self-efficacy, optimism and positive affectivity (Sheard & Golby, 2006). Perceptions of success were quantified through the use of the ‘Self-Perception of Quality of Performance Questionnaire’ (SPQPQ). The SPQPQ was originally developed by Ebbeck and Weiss (1988), who used the seven item survey to assess the ‘arousal-performance’ relationship in high school track and field athletes (n=51). The questionnaire utilises a ‘Likert’ scale (Likert, 1932) to quantify perceptions, which is an ordinal psychometric measurement of attitudes, beliefs and opinions. Sheard and Golby (2006) found that the psychological skills training program revealed significant performance improvement in three swimming strokes over 200m and an improvement in participants’ psychological profile. It can be inferred that positive attitudes and perceptions of a training program will have the potential to improve performance benefits. Consequently, a swimming training intervention that is beneficial to performance can be implemented successfully into habitual training if swimmers have a positive attitude towards it. Attitudes towards a swimming training program could then be assessed through the development of a modified SPQPQ to determine if it can be successfully integrated into habitual training.
2.4.6 Methodology in swimming start research summary

Analysis of training interventions on swimming start performance primarily focus on elite swimmers, with a paucity of studies that aim to improve performance in sub-elite adolescent swimmers (Table 1). Swimming start RT has been analysed through the use of video analysis (Blanksby et al., 2002), force plates (Benjanuvatra et al., 2004), a reaction pad (Balillionis et al. 2012) and infrared optical measurement technology (Lepretre et al., 2014). Of the thirteen studies listed in ‘Table 2’ only these four analyse RT, with the study carried out by Blanksby (2002) being the only study that involves a RCT study design. Analysis of potential changes to RT in response to a training intervention is vital to understanding the effect of RT training on swimming start performance. It is for this reason that development of a force measurement instrument operating at a sampling rate of 1000Hz, that measures the onset of force change being applied through the block, would be beneficial in the analysis of RT to the nearest millisecond.

2.5 Literature review summary

This chapter has provided a summary of the literature surrounding auditory RT, neuronal functional specificity to auditory stimuli, the ‘on-block’ phase of the swimming start and swimming start performance. Furthermore, this chapter has discussed training interventions that have been implemented with the goal of improving BT and take-off velocity, and their translatability to overall swimming start performance gains. Subsequently, previous training intervention studies and existing gaps in the literature have informed the focus and design of the study outlined in the following chapter (Chapter 3).
CHAPTER 3: METHODOLOGY

3.1 Participants

Sixteen male swimmers participated in this study. The cohort was limited to males to eliminate the possibility of results being confounded by gender differences. Prior to the testing period, ten sub-elite adolescent swimmers (14.0 ± 1.4 years) attended a minimum of four aquatic training sessions per week, for a minimum of one hour per session. Each of these participants had previously qualified for at least one event, of any stroke, at either age long course or age short course New South Wales state championships. An additional six national level swimmers (19.8 ± 1.0 years) from the same swimming club participated in the study. These elite level swimmers attended a minimum of six aquatic training sessions per week, for a minimum of one hour per session. They had previously qualified for at least one event, of any stroke, at age or open national championships.

The swimming club to which all participants belonged consisted of multiple squads training in an indoor 50m pool. The swimming centre had pre-existing OSB-11 competition diving blocks fixed on pool deck, on which the swimmers regularly practiced. All swimmers were given a verbal explanation of the study protocol and then given copies of the age specific information sheets and consent forms (Appendix 1). Those swimmers who consented to the study and had no current injuries or conditions that would be aggravated by regular dive practice were recruited in the study. The experimental procedure was approved by the University of Sydney’s Human Research Ethics Committee (HREC) (project number: 2015/518, Appendix 2).
3.2 Research design

A convenience sample approach was conducted after contact with the Sydney based swimming club. Eligible sub-elite adolescent swimmers who consented to the study were then randomly allocated, by a simple randomisation procedure (computerised random numbers), to either a control group (Cohort one: ‘C1’) (n=5, 13.4 ± 1.7 years) or intervention group (‘C2’) (n=5, 14.6 ± 0.9 years). Randomised controlled trial study designs are evident in swimming start performance literature (Bishop et al., 2009) as they show a stronger causality between an intervention and a performance result. Cohort one and C2 underwent a four week training intervention, where C1 completed a regular dive training program and C2 underwent a competition specific auditory stimulus dive training program. These training interventions were integrated into their habitual training regime by the swimmers’ regular coach who were briefed by the researcher on the training techniques prior to the commencement of the study. The researcher acted as a participant observer during the training period to limit any change to the swimmers’ habitual training.

Cohort three (‘C3’) consisted of the elite level swimmers within the same swimming club and were also recruited through a convenience sample approach. These swimmers continued their habitual training schedule with no change to their regular dive training. Swimming research has shown that elite level swimmers exhibit faster RTs in response to the starting auditory stimulus when compared with sub-elite swimmers (Vantorre et al., 2014). Therefore, C3 was included in the study to gain a baseline measure for RT and BT in elite level swimmers and to also compare against both cohorts of adolescent swimmers before and after the training intervention period.
3.3 Testing procedures

The study involved a four week training period for the sub-elite adolescent swimmers. Four weeks has been shown previously to be an adequate length of time to induce swimming start performance benefits (Hohmann et al., 2010). A summary of the two dive training interventions are outlined in Table 3. Swimming start testing occurred at the training site prior to the commencement of the training period for all cohorts and then again after the training period for C1 and C2. Study designs involving dive testing before and after a training intervention is consistent throughout swimming literature (e.g. Rebutini et al., 2014) as it shows, by comparison, possible changes in performance variables in response to the training intervention.

Table 3. Outline of implemented dive training interventions across two cohorts of sub-elite adolescent swimmers

<table>
<thead>
<tr>
<th>Control (C1)</th>
<th>Intervention (C2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Habitual dive training</td>
<td>Competition specific auditory stimulus training</td>
</tr>
<tr>
<td>- Six dives per session, three sessions per week (Blanksby et al., 2002)</td>
<td>- Six dives per session, three sessions per week</td>
</tr>
<tr>
<td>- Dive and sprint start to 15m (butterfly, breaststroke or front crawl)</td>
<td>- Dive and sprint start to 15m (butterfly, breaststroke or front crawl)</td>
</tr>
<tr>
<td>- Participants were instructed to perform starts at their own discretion without an auditory stimulus</td>
<td>- Commencement of swimming start with starting auditory stimuli “take your marks” and a ‘go’ signal (handheld electric horn)</td>
</tr>
<tr>
<td>- No technical feedback provided to the participants</td>
<td>- No technical feedback provided to the participants</td>
</tr>
</tbody>
</table>

To limit exposure of the starting auditory stimuli to C1, whilst swimmers in C2 were undertaking the training intervention, C1 was given a regular aquatic training set (at the coach’s discretion) in adjacent lanes.
Whitten (1997) found that butterfly swimmers would perform deeper dives during the underwater phase of a swimming start than freestyle swimmers. To limit any potential effect this may have on front crawl swimming start performance (‘time to 15m’) during the pre- and post-intervention testing sessions, participants were instructed to complete a minimum of three front crawl swimming starts during each of the training sessions. However, it should be noted that while differences exist during the underwater phases of different strokes, the above water parameters remain similar (Miller, Hay, & Wilson, 1984). Consequently, the RT and BT of the participants during the dive training sessions should not have been confounded by the stroke being performed after entering the water.

Dive testing sessions involved instructing each participant to perform three ‘race pace’ front crawl starts (diving from the instrumented OSB-11 block and sprinting to 15m), with normal competition auditory stimuli (speaker and electric horn). The distance between the auditory stimuli setup (speaker and electric horn) and the participant was controlled throughout each of the data collection points, to limit any possible startle response and alterations to the RT of the swimmers (Brown, Kenwell, Maraj, & Collins, 2008). During dive testing, swimming starts were carried out following a regular competition warm up, as this has been shown to achieve faster average 50yd freestyle times compared with shortened or no warm up (Balilionis et al., 2012). Following this, C1 and C2 were asked to complete a five minute written questionnaire (Table 5) to obtain general thoughts and attitudes associated with their dive training intervention, as well as a subjective look at potential performance gains.
3.4 Swimming start variables

The swimming start is considered as the first 15m of a race (Cossor, & Mason, 2001) and comprises four main phases; on-block 11% (0.74s), in-flight 5% (0.30s), underwater 56% (3.69s) and free swimming 28% (1.81s) (Mason et al., 2012). These phases informed the selection of the following quantitative measures of swimming start performance analysed in the current study:

1) Reaction time (RT) (s, to a thousandth of a second) - Time between the stimulus being presented and the change in ground reaction force (GRF) in response to muscular action (Johnson & Nelson, 1988).

2) Block time (BT) (s, to a thousandth of a second) - Time between the starting signal and the last moment of contact of the swimmer with the starting block (Blanksby et al., 2002).

3) Time to 15m (s, to a hundredth of a second) – Time between the starting signal and the vertex of swimmer’s head (Blanksby et al., 2002) reaching the 15m mark.

Each performance variable was reported as a single value derived from the mean of the three dives performed by each participant during the data collection sessions.

3.5 Data collection

The study assessed swimming start performance by analysing quantitative swimming start variables through the use of two different data collection instruments. Reaction time and BT were measured through an instrumented starting block with a custom built force measurement device (refer to 3.5.1). The swimmers’ ‘time to 15m’ were measured using a high speed camera (refer to 3.5.2). In addition to this, a written questionnaire using a five point Likert scale was administered post intervention (refer to 3.5.3).
3.5.1 Instrument: Force measurement device

A force measurement device was developed and constructed to register the onset of changes in GRF, reflecting the onset of movement of the participants during a swimming start. Development of the device was informed by previous swimming and athletics studies that have used force measurement devices such as Kistler force plates (Kistler Group, Switzerland) to accurately analyse RT, rather than measuring absolute force production (Willwacher et al., 2013; Pain & Hibbs, 2007; Lee et al., 2002; Mason et al., 2012). The force measurement device was constructed using piezo cabling (Figure 5). The cable is multi layered (Figure 6), with the piezo polymer layer acting as an electrical insulator (‘dielectric’). When the cable is stretched or compressed, polarisation of the piezo polymer occurs, producing a charge that is proportional to the stress (changes in force application by the swimmer) on the cable.

![Figure 5: Piezo cable image](Measurement Specialities, 2015)

![Figure 6: Internal structure of a piezo cable](Images Co, 2015)
The force measurement device comprised of two sections, one for each foot placement, with a single time series force output at 1000Hz. The force measurement device was designed to be portable and compatible for attachment to a regulation Omega OSB-11 starting block (Figure 7). Each of the two sections of the force platform involved two PVC sheets, with parallel internal channels that held the piezo cabling. The diameter of the internal channels were constructed to be the same size as the piezo cabling to create a tight seal and therefore be more sensitive to changes in force application to the surface of the force platform.

Figure 7: Omega OSB-11 starting block (Swiss Timing, 2009)

The force measurement device was tightly fitted to the OSB-11 starting block on the front of the deck, overlapping onto the toe edge of the block, and on the rear foot kicker using winch straps (Figure 8). This ensured that when participants performed a swimming start the force platforms did not shift under their feet. The surface of the force measurement device was painted with a non-slip paint to provide a rough surface similar to the regular surface of the block. Furthermore, the thickness of the device did not exceed 10mm and therefore did not significantly affect the height from which the swimmers were diving.
The piezo cable from the force measurement device connected to a battery operated (2 x 12V lead acid batteries) charge amplifier which was situated within a plastic tub for water proofing purposes and to ensure electrical safety whilst on pool deck (Figure 9). The voltage output from the charge amplifier was connected to a multi-channel converter which transferred the force data, via a USB cable, to a laptop computer. Audio data were collected via a wireless directional microphone positioned in front of the starting speaker (Figure 10). The directionality of the wireless microphone and positioning in the swimming centre was essential to reduce any possible background auditory noise and thus recorded clear and precise audio data. An audio receiver positioned in the plastic tub, connected to the multichannel converter, collected the auditory ‘go’ signal via the microphone.
Data from the force measurement device and the microphone were collected onto a laptop computer using National Instruments LabVIEW software (http://www.ni.com/labview) and included a timecode (in milliseconds) for post-performance analysis of RT and BT (3.6.1).
3.5.2 Instrument: High speed camera

A high speed camera, recording at 96Hz, was used for the analysis of ‘time to 15m’ of the swimmers during dive testing. A high frame rate was necessary to quantify ‘time to 15m’ to the nearest hundredth of a second, as competitive swimming races are also recorded to the nearest hundredth of a second. A Panasonic Lumix GH4 camera was positioned on a tripod at the 15m mark so that a metal pole positioned at 15m was visible (Figure 11). A light emitting diode (LED) linked with the starting device was positioned in the camera’s field of view and was used to assess the swimmers’ ‘time to 15m’, consistent with research conducted by Blanksby et al. (2002).

![Diagram of swimming start testing data collection setup](image)

**Figure 11:** Diagram of swimming start testing data collection setup

For each swimming start the camera operator began the recording with the 15-33mm camera lens set wide to include the flash from the starting LED in the field of view (Figure 11). Once the auditory ‘go’ signal occurred the camera operator then zoomed in, using the camera lens to narrow the field of view (Figure 11). As a result, time from the starting signal (LED flash) and the swimmer’s head reaching the 15m mark could be determined using video analysis software (refer to 3.6.2).
3.5.3 Instrument: Questionnaire

The written questionnaire (Table 4) completed by all swimmers in C2 was adapted from the ‘Self-Perception of Quality of Performance Questionnaire’ (SPQPQ), which was developed to determine swimmers’ perceptions of performance during training and competition (Ebbeck & Weiss, 1988). An identical questionnaire was also completed by C1, with the only change being the name “regular dive training” written in the title. The adapted questionnaire was designed to be in paper form so that it could be immediately given to participants upon completion of the training intervention. This ensured that perceptions of the training were ‘fresh in their minds’ when completing the questionnaire and also increased response rates when compared to an online questionnaire. However, it should be noted that no pressure was placed upon the participants to complete the questionnaire. The questionnaire was anonymous and consisted of nine questions with a five point ‘Likert’ scale (Likert, 1932). A Likert scale is an ordinal psychometric measurement of attitudes, beliefs and opinions and has been incorporated previously into a performance questionnaire in swimming by Ebbeck and Weiss (1988).
Table 4. Questionnaire (cohort 2): Perceptions of competition specific auditory stimulus dive training

**Instructions:** Answer each of the questions by circling one of the five responses for each question. This survey must be completed following your final dive testing session. **Do not** write your name on this sheet as your responses will remain anonymous.

1. Did you feel physically *fatigued* after each of the dive training sessions (i.e. after completing six dives)?
   1. Not at all
   2. A little bit
   3. Somewhat
   4. Quite a bit
   5. Very much

2. On average, how would you describe the amount of *effort* you gave during the dive training program?
   1. Hardly any
   2. A little bit
   3. Some
   4. Quite a bit
   5. Everything I had

3. How would you describe your mental *attitude* in relation to the four week training program?
   1. Very dissatisfied
   2. Dissatisfied
   3. Neutral
   4. Satisfied
   5. Very satisfied

4. On average, how would you describe the amount of *concentration* you gave during the dive training program?
   1. Hardly any
   2. A little bit
   3. Some
   4. Quite a bit
   5. Everything I had

5. Did you feel *confident* prior to the final testing session?
   1. Not at all
   2. A little bit
   3. Somewhat
   4. Quite a bit
   5. Very much

6. How would you describe your swimming start *performance* during the final testing session?
   1. One of the worst
   2. Below average
   3. Average
   4. Above average
   5. One of the best

7. How did your performance in the testing session compare to the way you *expected* to perform?
   1. Much worse than expected
   2. Worse than expected
   3. As expected
   4. Better than expected
   5. Much better than expected

8. Did you expect your reaction time to improve as a consequence of the training program?
   1. Not at all
   2. Not really
   3. Undecided
   4. Somewhat
   5. Very much so

9. Did you expect your time to 15 metres to improve as a consequence of the training program?
   1. Not at all
   2. Not really
   3. Undecided
   4. Somewhat
   5. Very much so
3.6 Data analysis

Data collected using the force measurement device and the high speed camera were analysed using computer software (‘Microsoft Excel’ and ‘Quicktime 7 Player’) to obtain a mean value of RT, BT and time to 15m for each participant pre- and post-intervention. It must be noted that any swimming starts with a RT < 0.1s (IAAF, 2016, “100 Metres”, para. 1; Pain & Hibbs, 2007) were deemed as the participant anticipating the starting signal and were not included in their mean RT, BT or ‘time to 15m’.

3.6.1 Data analysis: Force measurement device

Change in GRF allowed the researcher to identify the onset of muscular action by the swimmer and thus obtain RT in response to the starting signal to the nearest millisecond. Muscular action by the swimmer in response to the starting signal could result in an increase or a decrease in GRF. An increase in the charge output by the force instrument was indicative of a positive force application through the starting block by the lower limb muscles, whilst a decrease was the result of an unweighting response by the swimmer. Prior to the auditory ‘go’ signal occurring competitive swimming rules instruct the swimmer to remain stationary, resulting in the charge output from the force measurement instrument reaching a steady state. A positive or negative change in GRF produced by the swimmer from the established steady state indicated the point of reaction to the starting signal. Raw force and audio data for a dive were input into Microsoft Excel. The raw force data were then ‘smoothed’ using a single pass non-recursive moving average of seven data points. This was found to be more precise and reliable for the purpose of identifying the instant of exceeding the threshold than other digital filters with a longer span. The audio data and ‘smoothed’ force data were then graphed against ‘time’ to a thousandth of a second. Figure 12 represents an example of the change in force production during a swimming start in response to the auditory ‘go’
signal. The primary focus of the study was to analyse participant RTs rather than absolute force measurement. Therefore, it is to be noted that change in force production and the subsequent charge output by the force measurement device was recorded in arbitrary ‘units’ and not as a measurement of absolute force production in Newtons.

![Figure 12: Change in force production during a swimming start](image)

The researcher initially formatted the horizontal axis (Time) to view the first significant deflection point of the auditory data to estimate the beginning of the ‘go’ signal (Figure 13). Once the estimate is determined, the researcher then examined the audio data in its tabulated form. Examination of the auditory data throughout all of the participant dives informed the auditory ‘go’ signal selection criteria as the first instant when an audio data point was greater than ± 0.1 units.
The force data were then examined to determine the initiation of muscular activation in response to the ‘go’ signal. The gradient of the line between the two points either side of each time point was calculated and applied throughout the data series. In a similar fashion the researcher initially estimated the time point where the force data deviated from a steady state. Examination of the smoothed force data throughout all of the participant dives informed the RT selection criteria of this study. The point of reaction was deemed as the time point of the first instant of a deflection in the force data with the magnitude of the force gradient exceeding ± 1.5 units. Furthermore, the deflection point was required to have a continuing trend in the gradient above that threshold, for it to be deemed as the point of reaction. Table 5 demonstrates the point of reaction (shaded) of the dive previously shown in Figure 13.

**Figure 13:** Change in audio data in response to the auditory ‘go’ signal
Table 5. Determining the time point of muscular activation during a swimming start

<table>
<thead>
<tr>
<th>Time (Seconds)</th>
<th>Force data gradient (Units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.839</td>
<td>-0.911285714</td>
</tr>
<tr>
<td>10.84</td>
<td>-0.637928571</td>
</tr>
<tr>
<td>10.841</td>
<td>-0.364571429</td>
</tr>
<tr>
<td>10.842</td>
<td>-0.273428571</td>
</tr>
<tr>
<td>10.843</td>
<td>-0.546785714</td>
</tr>
<tr>
<td>10.844</td>
<td>-0.455714286</td>
</tr>
<tr>
<td>10.845</td>
<td>-0.273428571</td>
</tr>
<tr>
<td>10.846</td>
<td>0</td>
</tr>
<tr>
<td>10.847</td>
<td>-0.091071429</td>
</tr>
<tr>
<td>10.848</td>
<td>0.091214286</td>
</tr>
<tr>
<td>10.849</td>
<td>0.182285714</td>
</tr>
<tr>
<td>10.85</td>
<td>0.820142857</td>
</tr>
<tr>
<td>10.851</td>
<td>1.002428571</td>
</tr>
<tr>
<td>10.852</td>
<td>1.184642857</td>
</tr>
<tr>
<td>10.853</td>
<td>1.8225</td>
</tr>
<tr>
<td>10.854</td>
<td>1.8225</td>
</tr>
<tr>
<td>10.855</td>
<td>1.822428571</td>
</tr>
<tr>
<td>10.856</td>
<td>1.731357143</td>
</tr>
<tr>
<td>10.857</td>
<td>1.549142857</td>
</tr>
<tr>
<td>10.858</td>
<td>1.640214286</td>
</tr>
<tr>
<td>10.859</td>
<td>1.822428571</td>
</tr>
<tr>
<td>10.86</td>
<td>1.822428571</td>
</tr>
<tr>
<td>10.861</td>
<td>2.278071429</td>
</tr>
<tr>
<td>10.862</td>
<td>2.095857143</td>
</tr>
<tr>
<td>10.863</td>
<td>2.369214286</td>
</tr>
<tr>
<td>10.864</td>
<td>2.551428571</td>
</tr>
<tr>
<td>10.865</td>
<td>2.733642857</td>
</tr>
<tr>
<td>10.866</td>
<td>2.915857143</td>
</tr>
<tr>
<td>10.867</td>
<td>3.3715</td>
</tr>
<tr>
<td>10.868</td>
<td>4.556071429</td>
</tr>
<tr>
<td>10.869</td>
<td>6.014</td>
</tr>
<tr>
<td>10.87</td>
<td>6.743</td>
</tr>
<tr>
<td>10.871</td>
<td>7.1075</td>
</tr>
<tr>
<td>10.872</td>
<td>8.018785714</td>
</tr>
<tr>
<td>10.873</td>
<td>8.930071429</td>
</tr>
<tr>
<td>10.874</td>
<td>9.2945</td>
</tr>
<tr>
<td>10.875</td>
<td>9.2945</td>
</tr>
</tbody>
</table>

The last moment of contact of the swimmer with the block was deemed to be the instant at which the gradient was between -1.5 and 1.5 units and was followed by a plateau in the force data. The time points of the ‘go’ signal, point of reaction and the last moment of contact were then used to determine the RT and BT of the swimmer. Table 6 provides a summary of the selection criteria for each of the three time points.
Table 6. Summary of the analysis criteria for each significant time point during the ‘on-block’ phase

<table>
<thead>
<tr>
<th>Time point</th>
<th>Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) ‘Go’ signal</td>
<td>- Auditory data &lt; -0.1 or &gt; +0.1units</td>
</tr>
<tr>
<td>2) Point of muscular activation</td>
<td>- Deflection point</td>
</tr>
<tr>
<td></td>
<td>- Gradient of the force data (x): x &lt; -1.5 or x &gt; 1.5 units</td>
</tr>
<tr>
<td></td>
<td>- Continued trend in the gradient</td>
</tr>
<tr>
<td>3) Last moment of contact</td>
<td>- Gradient of the force data (x): -1.5 &lt; x &lt; 1.5 units</td>
</tr>
<tr>
<td></td>
<td>- Plateau in the force data</td>
</tr>
</tbody>
</table>

3.6.2 Data analysis: High speed camera

Video recordings of each dive were imported into the video viewing software ‘QuickTime 7 Player’. The software allows viewing of each recorded frame, which subsequently allowed the researcher to view the first frame depicting the LED flash and the frame where the vertex of the swimmer’s head reached the 15m mark. At each of these time points the QuickTime software provides a ‘frame number’ which was recorded. The frame number of the initial LED flash was subtracted from the frame number at the point of the apex of the swimmer’s head reaching the 15m mark. This value was then divided by 96 (as the camera was operating at 96Hz), to determine ‘time to 15m’ to the nearest one hundredth of a second. The mean ‘time to 15m’ values were then tabulated to compare the testing session time point(s) for each participant.
3.6.3 Data analysis: Questionnaire

Questionnaire responses were tallied and presented as the number of participant responses across the five point Likert scale for each of the nine questions. The number of responses was separated by cohort to compare differences in the perceptions of the two dive training interventions. The questionnaire results are discussed in Chapter 5 (Discussion) and Chapter 6 (Conclusions and Implications) as percentages of responses in conjunction with the quantitative swimming start variables.

3.7 Statistical analysis

The effect of the two dive training interventions on RT, BT and ‘time to 15m’ were statistically analysed separately for each of the quantitative variables. For each variable the main Time by Cohort interaction between C1 and C2 was analysed using a two factor mixed design ANOVA with two levels of within group factor (pre- and post-intervention). The effect of the dive training interventions on each cohort were further explored with contrasts comparing the swimming start variable means at each of the two time points using post-hoc paired sample T-tests. The magnitude of change from pre- to post-intervention was determined using ‘Cohen’s d’ index of effect size. The individual and cohort effect sizes were calculated using the pooled standard deviation of the within-subject variability (each participant had three trials enabling a pooled within subject variability to be determined). The effect size data supplemented the paired T-tests to look at the within individual and within cohort changes across pre and post-tests taking into account the within participant variability. This was useful in view of the small number of participants in each group and the strong chance of Type 1 and Type 2 errors when relying on T-tests in isolation. Additionally, independent samples T-Tests were then used to compare pre- and post-intervention sub-elite adolescent swimmers’ results with those from C3.
CHAPTER 4: RESULTS

4.1 Participant compliance

Swimmers in C1 completed an average of 44.2 ± 15.6 total dives over 8.0 ± 2.6 dive training sessions during the four week training period. Swimmers in C2 completed an average of 60.6 ± 15.0 total dives over 10.6 ± 2.1 dive training sessions. There is no significant difference between the total number of dives completed by participants in C1 versus C2 ($t = -1.698, p = .128$). Participant attendance during the training period and the number of dives completed by each individual swimmer in C1 and C2 are outlined in Table 7.

Table 7. Participant attendance and number of dives completed

<table>
<thead>
<tr>
<th>Participant (Cohort (C) #</th>
<th>Participant (P) #</th>
<th>No. of dive training sessions attended</th>
<th>Total dives completed</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1P1</td>
<td>10</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>C1P2</td>
<td>11</td>
<td>61</td>
<td></td>
</tr>
<tr>
<td>C1P3</td>
<td>6</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>C1P4</td>
<td>8</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>C1P5</td>
<td>5</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>C2P1</td>
<td>11</td>
<td>66</td>
<td></td>
</tr>
<tr>
<td>C2P2</td>
<td>7</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>C2P3</td>
<td>12</td>
<td>67</td>
<td></td>
</tr>
<tr>
<td>C2P4</td>
<td>12</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>C2P5</td>
<td>11</td>
<td>66</td>
<td></td>
</tr>
</tbody>
</table>
4.2 Swimming start data: Inclusion and exclusion

Dives with a calculated RT <0.1s (IAAF, 2016, “100 Metres”, para. 1) were considered to be an anticipation of the starting signal by the athlete and were therefore excluded from analysis of pre- and post-intervention changes in RT, BT and ‘time to 15m’, but are reported in Appendix 3. Consequently, throughout Chapter 4 mean values expressing RT, BT and ‘time to 15m’ do not include dives with an initial RT <0.1s, unless otherwise specified. Of the 78 total dives tested, 14 were removed due to anticipation of the starting signal (mean RT <0.1s: 0.076 ± 0.024). A further two dives were excluded due to human error, where the experimenter pressed an incorrect button for the force plate data collection. Furthermore, ‘time to 15m’ results from participant C3P1 were removed from the study as the swimmer had an upper limb injury and was unable to perform the ‘underwater’ and ‘free swimming’ phases of the swimming start at race pace.

4.3 Swimming start interventions: Summary of results

Table 8 summaries collected and analysed swimming start data for the each of the three variables for all participants at the pre- (week 0) and post-intervention (week 4) time points. Each value expressed in Table 8 is representative of a subject mean of the dives performed at a single dive testing session. Furthermore, Table 8 reports the magnitude of change as effect sizes, from pre- to post-intervention of the participants’ swimming start variables. It is to be noted that negative effect sizes are indicative of a faster post- than pre-intervention time.
<table>
<thead>
<tr>
<th>Participant</th>
<th>RT week 0 mean (s) ± SD</th>
<th>RT week 4 mean (s) ± SD</th>
<th>Cohort RT effect size (d)</th>
<th>BT week 0 mean (s) ± SD</th>
<th>BT week 4 mean (s) ± SD</th>
<th>Cohort BT effect size (d)</th>
<th>&quot;Time to 15m&quot; week 0 mean(s) ± SD</th>
<th>&quot;Time to 15m&quot; week 4 mean(s) ± SD</th>
<th>Cohort &quot;time to 15m&quot; effect size (d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1P1</td>
<td>0.146 ± 0.009</td>
<td>0.165 ± 0.008</td>
<td>1.57</td>
<td>0.790 ± 0.022</td>
<td>0.809 ± 0.029</td>
<td>0.18</td>
<td>9.58 ± 0.370</td>
<td>9.09 ± 0.061</td>
<td>-2.71</td>
</tr>
<tr>
<td>C1P2</td>
<td>0.130 ± 0.016</td>
<td>0.128 ± *</td>
<td>-0.16</td>
<td>0.759 ± 0.018</td>
<td>0.706 ± *</td>
<td>-0.49</td>
<td>7.96 ± 0.007</td>
<td>8.50 ± *</td>
<td>2.99</td>
</tr>
<tr>
<td>C1P3</td>
<td>0.148 ± *</td>
<td>0.165 ± 0.005</td>
<td>1.40</td>
<td>0.750 ± *</td>
<td>0.754 ± 0.010</td>
<td>0.04</td>
<td>7.85 ± *</td>
<td>8.08 ± 0.117</td>
<td>1.27</td>
</tr>
<tr>
<td>C1P4</td>
<td>0.131 ± 0.012</td>
<td>0.144 ± 0.016</td>
<td>1.07</td>
<td>0.844 ± 0.071</td>
<td>0.893 ± 0.022</td>
<td>0.45</td>
<td>7.94 ± 0.189</td>
<td>8.08 ± 0.021</td>
<td>0.77</td>
</tr>
<tr>
<td>C1P5</td>
<td>0.145 ± 0.004</td>
<td>0.145 ± 0.011</td>
<td>0.00</td>
<td>0.727 ± 0.028</td>
<td>0.676 ± 0.005</td>
<td>-0.47</td>
<td>8.34 ± 0.156</td>
<td>8.57 ± 0.189</td>
<td>1.27</td>
</tr>
<tr>
<td>Cohort Mean</td>
<td>0.140 ± 0.009</td>
<td>0.149 ± 0.016</td>
<td></td>
<td>0.774 ± 0.045</td>
<td>0.767 ± 0.086</td>
<td></td>
<td>8.33 ± 0.72</td>
<td>8.46 ± 0.42</td>
<td></td>
</tr>
<tr>
<td>C2P1</td>
<td>0.132 ± 0.009</td>
<td>0.110 ± 0.008</td>
<td>-1.81</td>
<td>0.729 ± 0.001</td>
<td>0.736 ± 0.010</td>
<td>0.06</td>
<td>7.20 ± 0.021</td>
<td>6.97 ± *</td>
<td>-1.27</td>
</tr>
<tr>
<td>C2P2</td>
<td>0.153 ± 0.016</td>
<td>0.137 ± 0.022</td>
<td>-1.32</td>
<td>0.784 ± 0.014</td>
<td>0.799 ± 0.030</td>
<td>0.14</td>
<td>7.92 ± 0.119</td>
<td>7.86 ± 0.145</td>
<td>-0.33</td>
</tr>
<tr>
<td>C2P3</td>
<td>0.130 ± 0.017</td>
<td>0.121 ± 0.011</td>
<td>-0.74</td>
<td>0.727 ± 0.003</td>
<td>0.689 ± 0.012</td>
<td>-0.35</td>
<td>7.30 ± 0.208</td>
<td>7.39 ± 0.050</td>
<td>0.50</td>
</tr>
<tr>
<td>C2P4</td>
<td>0.115 ± 0.010</td>
<td>0.115 ± 0.011</td>
<td>0.00</td>
<td>0.726 ± 0.015</td>
<td>0.736 ± 0.012</td>
<td>0.09</td>
<td>7.29 ± 0.021</td>
<td>7.41 ± 0.085</td>
<td>0.66</td>
</tr>
<tr>
<td>C2P5</td>
<td>0.127 ± 0.003</td>
<td>0.110 ± 0.009</td>
<td>-1.40</td>
<td>0.843 ± 0.033</td>
<td>0.789 ± 0.019</td>
<td>-0.50</td>
<td>8.11 ± *</td>
<td>8.46 ± 0.295</td>
<td>1.94</td>
</tr>
<tr>
<td>Cohort Mean</td>
<td>0.131 ± 0.014</td>
<td>0.119 ± 0.011</td>
<td></td>
<td>0.762 ± 0.052</td>
<td>0.750 ± 0.045</td>
<td></td>
<td>7.56 ± 0.42</td>
<td>7.62 ± 0.57</td>
<td></td>
</tr>
<tr>
<td>C3P1</td>
<td>0.114 ± 0.019</td>
<td>-</td>
<td>-</td>
<td>0.727 ± 0.018</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>C3P2</td>
<td>0.100 ± *</td>
<td>-</td>
<td>-</td>
<td>0.734 ± *</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>C3P3</td>
<td>0.110 ± *</td>
<td>-</td>
<td>-</td>
<td>0.737 ± *</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>C3P4</td>
<td>0.122 ± 0.014</td>
<td>-</td>
<td>-</td>
<td>0.664 ± 0.019</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>C3P5</td>
<td>0.127 ± 0.012</td>
<td>-</td>
<td>-</td>
<td>0.655 ± 0.014</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>C3P6</td>
<td>0.157 ± 0.012</td>
<td>-</td>
<td>-</td>
<td>0.689 ± 0.007</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cohort Mean</td>
<td>0.122 ± 0.020</td>
<td>-</td>
<td>-</td>
<td>0.701 ± 0.037</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>6.42 ± 0.10</td>
<td></td>
</tr>
</tbody>
</table>

*Mean value was representative of a single dive due to anticipation of the starting signal exclusions
4.4 The effect of competition specific auditory stimulus training on swimming start reaction time

The two factor mixed design ANOVA analysis revealed a significant Time by Cohort interaction (F = 14.668, p = .005, observed power = .917). The effect of the dive training interventions on each cohort was explored with contrasts comparing the RT means at each of the two time points. Reaction time results in C2 post-intervention were significantly faster than those pre-intervention at the 5% (0.05) significance level (t = 3.357, p = .028). The effect size of competition specific auditory stimuli training on C2’s RT was determined to be ‘large’ in magnitude (Sullivan & Feinn, 2012) (d = -.99). The cohort mean RT result in C1 post-intervention was slower than pre-intervention and approached statistical significance at the 5% (0.05) significance level (t = -2.153, p = .098). The magnitude of the change in RT in C1 approached a ‘large’ effect size (Sullivan & Feinn, 2012) (d = 0.74). Additionally, no significant differences in RT existed between C3 at Week 0 and C2 post-intervention (t = -.307, p = .766).
4.5 The effect of regular dive training and regular dive training with competition specific auditory stimulus on swimming start performance

The effect of regular dive training (C1) and competition specific auditory stimulus dive training (C2) on swimming start performance variables, BT and ‘time to 15m’, is summarised previously as cohort mean values in Table 8 and further analysed in 4.5.1 and 4.5.2.

4.5.1 Block time analysis

The two factor mixed design ANOVA analysis on participant BT data revealed that the Time by Cohort interaction was not significant (F = .052, p = .825, observed power = .055). The effect of Cohort was explored with contrasts comparing the BT means at each of the two time points. The analysis revealed that C1 and C2 BTs were not significantly different pre-intervention (t = .398, p = .701). Similarly, at the post-intervention time point C1 and C2 BTs were not significantly different (t = .409, p = .693). There were no significant differences in BT pre- to post-intervention in C1 (t = .320, p = .765) and C2 (t = .847, p = .445). Furthermore, there was no significant magnitude of effect of the training interventions on BT in either C1 (d = -.06) or C2 (d = -.011).

4.5.2 ‘Time to 15m’ analysis

The two factor mixed design ANOVA analysis on participant ‘time to 15m’ data revealed that the Time by Cohort interaction was not significant (F = .152, p = .707, observed power = .064). The effect of Cohort was explored with contrasts comparing the ‘time to 15m’ means at each of the two time points. The difference between C1 and C2’s ‘time to 15m’ results pre-intervention approached significance (t = 2.064, p = .073). At the post-intervention time point ‘time to 15m’ for C2 was significantly less than C1 (t = 2.687, p = .028). There were no significant differences in ‘time to 15m’
results pre- to post-intervention in C1 (t = -.768, p = .485) and C2 (t = -.559, p = .606). The magnitude of effect of the training interventions on ‘time to 15m’ approached a ‘large’ effect size (Sullivan, & Feinn, 2012) in C1 (d = .72) and was between ‘small’ and ‘medium’ effect size (Sullivan & Feinn, 2012) in C2 (d = .33).

4.6 Reaction times and block times of sub-elite and elite level swimmers

Reaction times and BTs of sub-elite adolescent swimmers (C1, n=5 and C2, n=5) were compared at the pre-intervention time point against results obtained from the elite level swimmers (C3, n=6). The difference in RTs between C1 and C3 approached statistical significance (t = 1.916, p = .088) at the p = 0.05 significance level, whilst RTs of C2 were not significantly different from C3 (t = .928, p = .377). BTs of C3 were significantly less than BTs of both C1 (t = 2.967, p = .016) and C2 (t = 2.287, p = .048).

4.7 Participant perceptions of swimming start training interventions

Table 9 summarises the post-intervention questionnaire results of the ten swimmers’ (C1: n=5, C2: n=5) perceptions towards each of the two swimming start training interventions. The results are presented as the number of responses across the five Likert scale response options for each question and is specific to each cohort. Differences existed in the participants’ mental attitude towards the two training interventions with all participants in C2 stating that they were ‘very satisfied’ with the program, whilst three participants in C1 revealed that were ‘satisfied’ and two stated they were ‘neutral’. 90% of all participants in C1 and C2 revealed they were confident prior to the final testing session and 90% of all participants believed that their RT results would improve as a result of their training intervention.
<table>
<thead>
<tr>
<th>Questions and number of participant responses per cohort</th>
<th>Cohort</th>
<th>1. Did you feel physically <em>fatigued</em> after each of the dive training sessions (i.e. after completing six dives)?</th>
<th>2. On average, how would you describe the amount of <em>effort</em> you gave during the dive training program?</th>
<th>3. How would you describe your mental <em>attitude</em> in relation to the four week training program?</th>
<th>4. On average, how would you describe the amount of <em>concentration</em> you gave during the dive training program?</th>
<th>5. Did you feel <em>confident</em> prior to the final testing session?</th>
<th>6. How would you describe your swimming start <em>performance</em> during the final testing session?</th>
<th>7. How did your performance in the testing session compare to the way you <em>expected</em> to perform?</th>
<th>8. Did you expect your reaction time to improve as a consequence of the training program?</th>
<th>9. Did you expect your time to 15 metres to improve as a consequence of the training program?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Did you feel physically <em>fatigued</em> after each of the dive training sessions (i.e. after completing six dives)?</td>
<td>C1</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>C2</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2. On average, how would you describe the amount of <em>effort</em> you gave during the dive training program?</td>
<td>C1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>C2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3. How would you describe your mental <em>attitude</em> in relation to the four week training program?</td>
<td>C1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>C2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4. On average, how would you describe the amount of <em>concentration</em> you gave during the dive training program?</td>
<td>C1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>C2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5. Did you feel <em>confident</em> prior to the final testing session?</td>
<td>C1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>C2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6. How would you describe your swimming start <em>performance</em> during the final testing session?</td>
<td>C1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>C2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7. How did your performance in the testing session compare to the way you <em>expected</em> to perform?</td>
<td>C1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>C2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8. Did you expect your reaction time to improve as a consequence of the training program?</td>
<td>C1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>C2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>9. Did you expect your time to 15 metres to improve as a consequence of the training program?</td>
<td>C1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>C2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
CHAPTER 5: DISCUSSION

Despite task specific training being shown to improve participant RTs when they are re-exposed to the same stimulus (Nuri et al., 2013; Gavkare et al., 2013; De Souza et al., 2013; Tong et al., 2009), the majority of current competitive swimmers do not conduct dive training with task specific auditory stimuli on a regular basis. Furthermore, current swimming literature is focussed on improving performance outcomes of elite athletes, with less attention being given to sub-elite adolescent swimmers who are the next generation of elite level swimmers. In this study it was hypothesised that the use of competition specific auditory stimuli during dive training could induce significant improvements in participant RTs, theoretically translating to improvements in participant BTs and overall swimming start performance.

Competition specific auditory stimulus dive training (C2) did result in improved participant RTs in response to the auditory ‘go’ signal when compared with regular dive training (C1). Whilst competition specific auditory stimulus training resulted in a statistically significant magnitude of RT change in C2, the effectiveness of this type of RT training can be explored through contrasts with other literature. Of the swimming start intervention studies previously discussed in Chapter 2, changes in RT before and after the implementation of a dive training intervention were analysed in only one (Blanksby et al., 2002). That study showed a cohort mean reduction in RT of 0.03s, after a regular dive training program, compared with the C2 cohort mean reduction of 0.012s in this study. Although the magnitude of change in RT was greater, Blanksby et al. assessment of RT was limited by the experimental design which involved the use of a high speed camera to determine the point of reaction. Reaction time was deemed to be the time between the start signal and the first instant of observable movement by the swimmer (Blanksby et al., 2002), rather than the time point of initial muscular activation (Johnson & Nelson, 1988). The current study determined RT through the use of a
force measurement instrument, which ensured that the initial point of muscular activation was being assessed.

Whilst only a single swimming start intervention study assessed changes in RT prior to the current study, other sporting and non-sporting literature can provide insight into RT training techniques. A competitive swimming start shares similar auditory starting stimuli characteristics with that of an athletics track start. Extensive research has been conducted in athletics involving analysis of sprinters’ RTs during a sprint start (Nuri et al., 2013; Willwacher et al., 2013; Pain & Hibbs, 2007; Delalija & Babić, 2008). In these studies, associations between specific physiological characteristics of sprinters and RT, as well as the effect of faster RTs on sprint performance, were assessed. However, the effect of training interventions on RT was not assessed in these studies and is an area of research that remains sparse. On the other hand, RT training interventions have been evident in non-sporting literature. A twelve week yoga training intervention was implemented in a group of male medical students (n=27), to assess its effect on auditory RTs (Madanmohan et al., 1992). The yoga training resulted in significantly faster auditory RTs by the students, with a mean reduction of 0.037s from pre- to post-intervention. This improvement was suggested to be due to improved concentration and ability to filter out extraneous stimuli. A reduction of 0.037s in RT represents a greater magnitude of RT change than what was found in the current study. It is to be noted however, that the sub-elite adolescent swimmers in the current study were already trained in the act of swimming starts prior to the intervention, highlighting that the training intervention in C2 resulted in faster RTs despite the participants’ prior skill level. Consequently, the use of competition specific auditory stimuli during habitual dive training was an effective method of reducing swimming start RT by up to 0.022s (C2P1), over a short period of training intervention.
While competition specific auditory stimulus dive training resulted in a significant reduction in C2’s RT results, no statistically significant differences were found between C2 and C3 RT results pre- and post-intervention. This result did not coincide with our hypothesis which stated that auditory stimulus dive training would be implemented to bridge the performance gap between sub-elite and elite level swimmers’ RTs. Analysis of only the sub-elite swimmers’ (n = 10) ‘time to 15m’ and RT results showed a moderate correlation (r = .513) between these two swimming start variables which was consistent with previous research (Vantorre et al., 2014). However, a higher competitive swimming level of the participants in the current study did not necessarily predict significantly faster RT results.

Regular dive training in C1, with the absence of any auditory stimuli, resulted in an undesirable effect on participant RTs. The magnitude of change from pre- to post-intervention came close to a ‘large’ effect size in the direction of slower participant RT results, which approached statistical significance (p = .098). The change in RTs of C1 did not coincide with previous regular dive training research which revealed, in the absence of an auditory ‘go’ stimulus, that regular dive training can improve swimming start RT (Blanksby et al., 2002). Although the majority of daily swimming programs involve habitual dive training without competition specific auditory stimuli, swimmers are regularly exposed to variations of their coach’s voice as an auditory stimulus. Commonly spoken phrases used by coaches to commence a swimming start during habitual dive training are “ready” or “take your marks”, followed by “go”. The pre- to post-intervention RT results of C1 may be explained by removal of all forms of auditory stimulus when performing dive training. While a coach’s voice and an electronic horn differ in their audio frequency, the results potentially suggest that dive training with the coach’s voice is more advantageous than the act of performing dives without any auditory stimuli.
Participant perceptions of a training intervention may affect their mental attitude throughout the training period, resulting in altered final dive testing RT results. The study carried out by Sheard and Golby (2006) showed that a psychological skills training program can be used to improve overall swimming performance (race times). Consequently, it could be anticipated that if participants in C1 and C2 had a positive psychological view of the effect of the training programs on RT, then they would be more likely to apply maximal effort during the dive training sessions, resulting in improved swimming start performance. ‘Mental attitude’ towards the dive training program was quantified in the final testing session written questionnaire and revealed that 100% of C2 were ‘very satisfied’ with the intervention, whilst C1 responded as either ‘neutral’ (n=2) or ‘satisfied’ (n=3). The difference in ‘mental attitude’ may have been due to participants in C1 perceiving their training program and the associated cohort as the control group. Despite this, 100% of participants in C1 believed that their RT would improve ‘somewhat’ or ‘very much so’, suggesting that the changes in RT results in C1 and C2 were less confounded by the participant’s perceptions of the training programs and rather, were brought about by the dive training programs themselves. Furthermore, the swimming training carried out by the sub-elite swimmers in C1 and C2 during the four week intervention may have altered final dive testing results. However, despite any potential effect of the swimming training, competition specific auditory stimulus dive training had a positive effect on swimming start RTs of C2.

Although the magnitude of RT change in C2 had a ‘large’ cohort effect size, the relative magnitude of the benefit of faster RTs to swimming start performance (BT and ‘time to 15m’) needs to be considered. Competitive swimming start times to 15m have been found to vary from 0.8% to 26.1% of the overall race time, depending on the event (Cossor & Mason, 2001). Consequently, as BT is comprised of RT and movement time of the swimmer, faster RTs would theoretically reduce BT and assist in improving overall race performance, especially in shorter distance events. Interestingly, despite the training interventions resulting in faster RTs in C2 and slower RTs in C1, no significant
changes in BT were evident pre- to post-intervention in either cohort. This result may be due to the fact that a reduction in C2’s mean cohort RT of 0.012s represents a mere 1.6% of the post-intervention cohort mean BT. Therefore, minute changes in RT would not yield a statistically significant change in BT. However, no apparent trend existed between RT effect sizes and BT effect sizes within participants, inferring that improvements in RT results did not necessarily result in faster BTs. Previous research has shown that the application of pre-tension of the lower limb muscles through the starting block prior to the starting signal has significantly reduced BTs compared to no pre-tension (Lee et al., 2002). Pre-tension of the lower limb muscles, or static muscle contractions, whilst on the block resulted in reduced time to peak force. As a result, rate of force development (RFD) through the lower limb muscles during a swimming start may be a superior indicator of faster BTs than the time point of initial muscular activation.

While the magnitude of change in RT was statistically significant in C2 and the cohort effect sizes of C1 and C2 were in opposite directions, it is to be noted that RT represents a very small percentage of the overall ‘time to 15m’. While changes in RT did not yield statistically significant changes in ‘time to 15m’ results in either C1 or C2, faster RTs in a competitive setting may still have an effect on the overall race outcome. No significant changes in ‘time to 15m’ results in the current study differed with previous research, where the integration of dives into regular training, in the absence of any auditory stimuli, had previously shown improvements in elite level swimmers’ ‘time to 10m’ results (Blanksby et al., 2002). This difference in research findings may be due to the differing competitive level of the sample groups.

The study conducted by Mason et al. (2012) found that of the ‘time to 15m’, elite-level swimmers (n=52) spent 56% in the underwater phase and 28% in the free swimming phase. The sub-elite adolescent swimmers in the current study were observed by the researcher to spend a greater percentage of time in the free swimming phase than the elite-level swimmers. ‘Time to 15m’ results
were potentially confounded by the swimmers’ regular swimming training during the intervention period which may have altered free swimming velocity and therefore made it difficult to draw any causal effect of the dive training interventions on swimmers’ ‘time to 15m’ results.

Elite level swimmers in C3 were not subject to competition specific auditory stimulus during their dive training. Despite this, their pre-intervention RT results were not significantly different from C2’s post-intervention results. The RT results in C3 may be attributable to the culmination of total dives performed during competitions over their swimming career, which would involve reacting to the competition auditory stimuli. In addition to this, performing a large quantity of dives at a competitive level may also assist the swimmers in concentrating on the starting auditory stimulus and filtering out extraneous stimuli. Therefore, elite swimmers may produce faster RTs with a greater concentration and less nervous system processing whilst on the block than elite sprint athletes (Maglischo, 1982). The RT results of the elite level swimmers in C3 (0.122 ± 0.020) were also fast when compared with the mean RT of 0.164 ± 0.024s taken from 76 male 100m athletics sprinters at the 2004 Olympic Games in Athens (Delalija & Babić, 2008). Unlike competitive swimming, starting blocks in athletics are fitted with a false start system with force sensors operating at 1000Hz which are designed to alert the starter when a runner has applied force prior to 0.1s after the starting signal. As a result, athletics sprinters may have a further neural processing barrier when reacting to the auditory ‘go’ stimulus, to ensure a false start does not occur. The difference in RTs between the swimmers in C3 and athletics sprinters may also be due to the swimmers undergoing RT analysis in a training environment, where there is no apprehension or consequences of a false start. Furthermore, without a force application false start system in place in competitive swimming, swimmers may not be as hesitant when reacting to the starting signal as that of athletics sprinters and may be applying pre-tension through the lower limb muscles prior to the starting signal.
The elite level swimmers’ BT results (0.701 ± 0.037s) in this study were consistent with previous swimming start research which found elite level male swimmers had an average BT of 0.72 ± 0.04s (Tor et al., 2015). A higher competitive level of swimming appears to be associated with faster BTs whereby, at the pre-intervention dive testing session C3 had significantly faster BT results than both C1 (0.774 ± 0.045s) and C2 (0.762 ± 0.052s). A competitive swimming start has an auditory ‘go’ signal similar to the start protocol in athletics and also shares similar kinematic properties to that of an athletics block start after the introduction of the OSB-11 rear kick plate. Analysis of the block starts in athletics have shown that the RFD of the lower-limb muscles was significantly greater in elite sprinters than sub-elite sprinters and that muscular strength plays a significant role in the efficiency of a sprint start (Slawinski et al., 2010). Additionally, Sleivert and Taingahue (2004) analysed the relationship between sprint start variables and strength and power of 30 male athletes, concluding that concentric force development is essential to sprint start performance. Consequently, the performance gap in BTs of elite and sub-elite level swimmers may be attributable to a greater muscular strength and RFD.

Habitual aquatic and resistance training, competitive swimming level and the associated physiological characteristics of the age gap may all contribute to a greater RFD and maximal strength in the elite level swimmers in the current study when compared with the sub-elite adolescent swimmers. Research conducted in the sport of badminton, which also requires maximal and explosive muscle strength, showed that a group of elite male badminton players (n=35) had a significantly greater RFD in the muscles flexing and extending the knee joint, than a reference group of males who conducted a 14 week resistance training program (Andersen, Larsson, Overgaard, & Aagaard, 2007). The study concluded that this finding might be due to physiological adaptations brought about by the habitual training undertaken by the badminton players. Training interventions have also been shown to result in changes to RFD, as seen in a group of 15 male subjects increasing their contractile RFD after a heavy-resistance strength training program (Aagaard, Simonsen,
Andersen, Magnusson, & Dyhre-Poulsen, 2002). Furthermore, habitual aquatic training undertaken by participants in C1 and C2, coupled with the dive training interventions, may have had little to no effect on the RFD and maximal strength of the sub-elite adolescent swimmers.

This chapter discussed the effect of competition specific auditory stimulus training on swimming start RT and overall swimming start performance, to which a number of conclusions and implications can be made. These conclusions and implications are presented in the following chapter (Chapter 6).
CHAPTER 6: CONCLUSIONS AND IMPLICATIONS

6.1 Conclusions

It was concluded, from the findings of the current study, that competition specific auditory stimulus dive training is an effective training technique to improve swimming start RT. Furthermore, regular dive training in the absence of an auditory ‘go’ stimulus (coach’s voice or electronic horn) was detrimental to swimming start RT. The current study found that competitive swimming level was not a clear predictor of swimming start RT, whereby RTs were subject to participant variability across the sample group. Additionally, participants across all three cohorts displayed fast RTs when compared with competition recorded RTs of track sprinters. It was concluded that a further neural processing ‘barrier’ may exist for track sprinters when reacting to the auditory ‘go’ signal in competition. Unlike athletics, competitive swimming does not have a clear force measurement false start mechanism, which may have accounted for the swimmers’ RTs in the current study.

While competition specific auditory stimulus dive training was effective in reducing RT, it had no statistically significant effect on overall swimming start performance in sub-elite adolescent swimmers. However, an improvement in swimming start RT of 0.012s (C2 pre- to post-intervention mean reduction) has the potential to effect performance and overall race outcomes at an elite international level, especially in short distance events. For example, altered RTs during the women’s 100m freestyle final at the Olympic Games in Rio de Janeiro (Brazil, 2016) may have changed the final race outcome, where Simone Manuel (USA) and Penny Oleksiak (Canada) tied for the gold medal with a time of 52.70s.
Questionnaire findings from the current study revealed that all of the sub-elite participants indicated that they were only ‘a little bit’ or ‘somewhat’ fatigued after each dive session and 100% of C2 indicated that their mental attitude towards the task specific dive training was ‘very satisfied’. From a coaching perspective, the questionnaire findings highlighted that this type of dive training is implementable into habitual aquatic training. The findings of the current study have implications for coaching staff across all competitive levels of swimming, whereby incorporating competition specific auditory stimuli during habitual dive training has the potential to develop optimal swimming start RTs in their athletes.

6.2 Limitations and future directions

The current study aimed to fill the gap in the literature surrounding the use of RT training interventions in the sport of swimming. The study has provided preliminary findings for the use of task specific dive training, with auditory components, as an effective form of RT training for competitive swimmers. The research has significantly contributed to the understanding of swimming start RT and holds implications for further investigations with the goal of improving swimming performance at an elite international level.

Given that the current study was limited by a small sample size, further research involving larger sample sizes and the regimented implementation of the intervention into habitual training, to increase participant adherence, would be beneficial to investigate the effect of this form of RT training on overall performance outcomes. Additionally, further research involving a sample of female participants would be advantageous to assess possible RT gender variations in response to auditory RT training. Specifically to swimming, the inclusion of ‘time to 5.5m’ (Bishop et al., 2009) as an additional performance variable would be ideal to limit the ‘underwater’ and ‘free swimming’ phases from confounding any potential effect of RT improvements on overall swimming start
performance. Although the time between “take your marks” and the auditory ‘go’ signal is variable, analysis of starts in a training environment holds no negative consequence to the participant if they ‘false start’ and therefore increases the likelihood of the participant anticipating the starting signal. This concept was apparent in the current study, whereby a number participant RT results were removed due to anticipation of the starting signal. Consequently, a future study that involved a greater number of starts during testing sessions would be beneficial to reduce the effect of data removal, due to anticipation of the starting signal, on participant mean values.

Significant changes to swimming start performance in competitive adolescent swimmers may have been limited by their RFD, maximal force production off the starting block and ‘free swimming’ performance. Therefore, the current study holds implications for further research with sub-elite swimmers and athletics sprinters, involving task specific start training coupled with age specific resistance training, to improve force capabilities of adolescent athletes. Further research is also required to investigate whether auditory RT training would be beneficial in elite level swimmers and athletics sprinters, who already have an optimal RFD and maximal force brought about through their greater load and volume of habitual training, cross-training (e.g. resistance training) and age specific physiological development.

The unique force measurement device developed and used in the current study was effective in analysing swimming start RT, portable and easily operable by the researcher. Additionally, as the device was battery operated and waterproofed, it adheres to safety procedures associated with electrical equipment in a pool environment. Consequently, the force measurement device is a significant contribution to the sport of swimming, not only holding implications for further swimming start research, but also by providing a more economically viable and precise method of RT analysis for competitive swimmers and coaching staff. Furthermore, the device has implications for
the development of a false start detection system for competitive swimming, similar to that used in athletics.

Knowledge gained from this study significantly contributes to the understanding of auditory RT training and the development of optimal swimming start RTs of competitive swimmers. Furthermore, the current research has implications for the further exploration of auditory RT training in swimming at an elite level and other sporting codes that involve reacting to an auditory stimulus.
REFERENCES


APPENDICES

Appendix 1: Participant information sheets and consent forms

Participant information sheet (adolescent swimmer):

The effect of competition specific auditory stimulus training on swimming start reaction time

PARTICIPANT INFORMATION STATEMENT

(1) What is this study about?

The University of Sydney invites you to take part in a study that will involve the recreation of a competition specific environment in the regular training setting. Regular dive practice under these conditions will be performed to investigate whether reaction time can be improved, with the ultimate goal of improving overall swimming performance. Please note that this information sheet should also be shown to your parent or guardian.

(2) Who is running the study?

The study is being conducted by Christopher Papic and Professor Ross Sanders at the University of Sydney.
What will the study involve for me?

If you consent to your involvement in the study, the researcher will randomly allocate you to one of two groups if you are between the ages of 12-17. The study will involve a four week training period and two dive testing sessions. The two dive training groups are outlined in the table below.

<table>
<thead>
<tr>
<th>Group</th>
<th>Training Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Swimmers will perform six dives a session, three times per week (18 dives/week), for four weeks. This will involve diving without a starting signal and sprinting to 15m.</td>
</tr>
<tr>
<td>2</td>
<td>Swimmers will perform six dives a session, three times per week (18 dives/week), for four weeks. This will involve diving after “take your marks” and the “go” signal and sprinting to 15m.</td>
</tr>
</tbody>
</table>

A dive testing session will occur before and after the four week training program to measure possible changes in reaction time and time to 15m. This will involve three ‘race pace’ dives (sprint to 15m) by each swimmer after a regular competition warm-up. Reaction time will be analysed using a plastic mat with an internal wiring, which will be attached to the surface of the block. This device will be battery operated, with no mains electricity connection and no safety hazard. The device will allow the research team to analyse the time between the starting buzzer and the first movement of the leg muscles (reaction time). A high speed camera will also be setup at the 15m mark to measure swimming time to 15m (note: the video recordings will only be accessible by the research team and will only be used to determine time to 15m). Group two will also be asked to complete a short questionnaire to provide feedback about the general thoughts and attitudes associated with the training technique. Your reaction time and time to 15m will also be compared to a group of elite level swimmers from your swimming club to measure the difference between adolescent and elite level swimmers before and after the training program.

How much of my time will the study take?

You will be required to attend an initial testing session and then complete the four week training program you are allocated to. This training program will be implemented in your normal training
program by your coach, involving dive training on three days a week. Following the training period a final testing session will occur. Group two will also be asked to complete a short written questionnaire which will take less than five minutes to complete. Testing sessions: Require swimmers to attend dive testing at the beginning of pre-scheduled normal training session.

(5) Who can take part in the study?
Swimmers aged 12-17 who are regularly training and competing. Participants with a current injury or a condition that will be aggravated by regular dive practice will be excluded from the study. Reaction times of elite level swimmers are faster than that of competitive adolescent swimmers. Group one and two will consist of adolescent swimmers (aged 12-17) and will aim to determine whether reaction time can be improved with a dive training program and breach the gap between elite level swimmers (aged 18 or over).

(6) Do I have to be in the study? Can I withdraw from the study once I've started?
Participation is voluntary and if you consent to your involvement you have the ability to withdraw from the study at any time without consequence and without affecting your relationship with your Swimming club, coach and the University of Sydney.

(7) Are there any risks or costs associated with being in the study?
There is always a potential risk of injury during swimming starts; however competitive swimmers are well learned in the skill of diving. Therefore, the risk of potential injury in this study is no greater than that of the normal training schedule. Additionally, participants with a current injury or a condition that will be aggravated by regular dive practice will be excluded from the study.
(8) Are there any benefits associated with being in the study?

Competition specific dive training and regular dive training may potentially improve reaction time and time to 15m. This could result in the implementation of a dive training program within your regular training schedule that will aim to improve swimming performance.

(9) What will happen to information about me that is collected during the study?

By providing your consent, you are agreeing to us collecting personal information about you for the purposes of this research study. Your information will only be used for the purposes outlined in this Participant Information Statement, unless you consent otherwise. Information will be stored securely and your identity/information will be kept strictly confidential, except as required by law. Study findings may be published, but you will not be individually identifiable in these publications. We will keep the information we collect for this study, and we may use it in future projects. By providing your consent you are allowing us to use your information in future projects. We don’t know at this stage what these other projects will involve. We will seek ethical approval before using the information in these future projects. With your consent your coach/es will have access to your personal results (reaction time and time to 15m).

(10) Can I tell other people about the study?

Yes, you are welcome to tell other people about the study.

(11) What if I would like further information about the study?

When you have read this information, Christopher Papic will be available to discuss it with you further and answer any questions you may have. If you would like to know more at any stage during the study, please feel free to contact Christopher Papic (T: 0421 519 172, E: cpap5310@uni.sydney.edu.au).
(12) **Will I be told the results of the study?**

You have a right to receive feedback about the overall results of this study. You can tell us that you wish to receive feedback by ticking the relevant box on the consent form. This feedback will be in the form of a written summary letter. You will receive this feedback after the study is finished.

(13) **What if I have a complaint or any concerns about the study?**

Research involving humans in Australia is reviewed by an independent group of people called a Human Research Ethics Committee (HREC). The ethical aspects of this study have been approved by the HREC of the University of Sydney [project number: 2015/518]. As part of this process, we have agreed to carry out the study according to the *National Statement on Ethical Conduct in Human Research (2007)*. This statement has been developed to protect people who agree to take part in research studies. If you are concerned about the way this study is being conducted or you wish to make a complaint to someone independent from the study, please contact the university using the details outlined below. Please quote the study title and protocol number.

The Manager, Ethics Administration, University of Sydney:

- **Telephone:** +61 2 8627 8176
- **Email:** ro.humanethics@sydney.edu.au
- **Fax:** +61 2 8627 8177 (Facsimile)

This information sheet should be shown to your parent or guardian and is for you to keep
Participant information sheet (elite level swimmer):

The effect of competition specific auditory stimulus training on swimming start reaction time

PARTICIPANT INFORMATION STATEMENT

(1) What is this study about?

The University of Sydney invites you to take part in a study that will involve the recreation of a competition specific environment in the regular training setting. Regular dive practice under these conditions will be performed to investigate whether reaction time can be improved, with the ultimate goal of improving overall swimming performance.

(2) Who is running the study?

The study is being conducted by Christopher Papic and Professor Ross Sanders at the University of Sydney.

(3) What will the study involve for me?

If you consent to your involvement in the study, you will be placed in group three (elite level). This will involve a single swimming start testing session, will no change to your normal training regime.

Discipline of Exercise and Sport Science

Professor Ross Sanders

Room C43K
K Block, Cumberland Campus
The University of Sydney
NSW 2006 AUSTRALIA
Telephone: +61 2 9351 9067
Facsimile: +61 2 9351 9204
Email: ross.sanders@sydney.edu.au
Web: http://www.sydney.edu.au/
Three ‘race pace’ dives (sprint to 15m) will be performed by each participant after a regular competition warm-up. Reaction time will be analysed using a plastic mat with an internal wiring, which will be attached to the surface of the block. The device will be low-voltage battery operated, with no mains electricity connection and no safety hazard. This mat will measure force being applied through the starting block. This device will allow the research team to analyse the time between the starting buzzer and the first activation of the muscles (reaction time), as well as the total time spent on the block. These values will then be compared to two groups of adolescent swimmers following the four week training period they will undertake. Additionally, a high speed camera will also be setup at the 15m mark to measure swimming time to 15m (note: these recordings will only be accessible by the research team and will only be used to determine time to 15m).

(4) How much of my time will the study take?
You will be required to attend a single dive testing session at an allocated swimming centre at a pre-scheduled time (specific to each swimmer).

(5) Who can take part in the study?
Swimmers aged 18 or over at an ‘open national level’. Participants with a current injury or a condition that will be aggravated by regular dive practice will be excluded from the study. Reaction times of elite level swimmers are faster than that of competitive adolescent swimmers. Groups one and two will consist of adolescent swimmers (aged 13-17) and will aim to determine whether reaction time can be improved with a dive training program and breach the gap between elite level swimmers (aged 18 or over).
(6) Do I have to be in the study? Can I withdraw from the study once I've started?

Participation is voluntary and if you consent to your involvement you have the ability to withdraw from the study at any time without consequence and without affecting your relationship with your Swimming club, coach and the University of Sydney.

(7) Are there any risks or costs associated with being in the study?

There is always a potential risk of injury during swimming starts; however competitive swimmers are well learned in the skill of diving. Therefore, the risk of potential injury in this study is no greater than that of the normal training schedule. Additionally, participants with a current injury or a condition that will be aggravated by regular dive practice will be excluded from the study.

(8) Are there any benefits associated with being in the study?

Competition specific dive training and regular dive training may potentially improve reaction time and time to 15m. This could result in the implementation of a dive training program within your regular training schedule that will aim to improve swimming performance.

(9) What will happen to information about me that is collected during the study?

By providing your consent, you are agreeing to us collecting personal information about you for the purposes of this research study. Your information will only be used for the purposes outlined in this Participant Information Statement, unless you consent otherwise. Information will be stored securely and your identity/information will be kept strictly confidential, except as required by law. Study findings may be published, but you will not be individually identifiable in these publications. We will keep the information we collect for this study, and we may use it in future projects. By providing your consent you are allowing us to use your information in future projects. We don’t know at this stage what these other projects will involve. We will seek ethical approval before using
the information in these future projects. With your consent your coach/es will have access to your personal results (reaction time and time to 15m)

(10) Can I tell other people about the study?
Yes, you are welcome to tell other people about the study.

(11) What if I would like further information about the study?
When you have read this information, Christopher Papic will be available to discuss it with you further and answer any questions you may have. If you would like to know more at any stage during the study, please feel free to contact Christopher Papic (T: 0421 519 172, E: cpap5310@uni.sydney.edu.au).

(12) Will I be told the results of the study?
You have a right to receive feedback about the overall results of this study. You can tell us that you wish to receive feedback by ticking the relevant box on the consent form. This feedback will be in the form of a written summary letter. You will receive this feedback after the study is finished.

(13) What if I have a complaint or any concerns about the study?
Research involving humans in Australia is reviewed by an independent group of people called a Human Research Ethics Committee (HREC). The ethical aspects of this study have been approved by the HREC of the University of Sydney [project number: 2015/518]. As part of this process, we have agreed to carry out the study according to the National Statement on Ethical Conduct in Human Research (2007). This statement has been developed to protect people who agree to take part in research studies. If you are concerned about the way this study is being conducted or you wish to make a complaint to someone independent from the study, please contact the university using the details outlined below. Please quote the study title and protocol number.
The Manager, Ethics Administration, University of Sydney:

- **Telephone**: +61 2 8627 8176
- **Email**: ro.humanethics@sydney.edu.au
- **Fax**: +61 2 8627 8177 (Facsimile)

*This information sheet is for you to keep*
Consent form (participant):

The effect of competition specific auditory stimulus training on swimming start reaction time

PARTICIPANT CONSENT FORM

I, ................................................................. [PRINT NAME], agree to take part in this research study.

In giving my consent I state that:

✓ I understand the purpose of the study, what I will be asked to do, and any risks/benefits involved.

✓ I have read the Participant Information Statement and have been able to discuss my involvement in the study with the researchers if I wished to do so.

✓ The researchers have answered any questions that I had about the study and I am happy with the answers.

✓ I understand that being in this study is completely voluntary and I do not have to take part. My decision whether to be in the study will not affect my relationship with the researchers, anyone else at the University of Sydney or with my swimming club, now or in the future.

✓ I understand that I can withdraw from the study at any time.
I understand that my questionnaire responses cannot be withdrawn once they are submitted, as they are anonymous and therefore the researchers will not be able to tell which one is mine.

I understand that personal information about me that is collected over the course of this project will be stored securely and will only be used for purposes that I have agreed to. I understand that information about me will only be told to others with my permission, except as required by law.

I understand that the results of this study may be published, and that publications will not contain my name or any identifiable information about me.

I consent to:

- Video-recording
  YES ☐ NO ☐

- Being contacted by members of the research team about future studies
  YES ☐ NO ☐

- My coach/es having access to my personal results (reaction time and time to 15m)
  YES ☐ NO ☐

Would you like to receive feedback about the overall results of this study?

YES ☐ NO ☐

If you answered YES, your associated swimming coach will be given copies of the summary sheets and will give them to you in person.

.......................................................... ..........................................................
Signature Print name Date

.......................................................... ..........................................................
.......................................................... ..........................................................
Consent form (parent/carer):

PARENT/CARER CONSENT FORM

I, ................................................................................... [PRINT PARENT’S/CAREER’S NAME], consent to my child ................................................................................... [PRINT CHILD’S NAME] participating in this research study.

In giving my consent I state that:

✓ I understand the purpose of the study, what my child will be asked to do, and any risks/benefits involved.

✓ I have read the Information Statement and have been able to discuss my child’s involvement in the study with the researchers if I wished to do so.

✓ The researchers have answered any questions that I had about the study and I am happy with the answers.

✓ I understand that being in this study is completely voluntary and my child does not have to take part. My decision whether to let them take part in the study will not affect our relationship with the researchers or anyone else at the University of Sydney or with my swimming club, now or in the future.
✓ I understand that my child can withdraw from the study at any time.

✓ I understand that my child’s questionnaire responses cannot be withdrawn once they are submitted, as they are anonymous and therefore the researchers will not be able to tell which one is mine.

✓ I understand that personal information about my child that is collected over the course of this project will be stored securely and will only be used for purposes that I have agreed to. I understand that information about my child will only be told to others with my permission, except as required by law.

✓ I understand that the results of this study may be published, and that publications will not contain my child’s name or any identifiable information about my child.

I consent to:

- Being contacted by members of the research team about future studies involving my child

  YES ☐ NO ☐

- Video-recording of my child

  YES ☐ NO ☐

- My child’s coach/es having access to their personal results (reaction time and time to 15m)

  YES ☐ NO ☐

Would you like to receive feedback about the overall results of this study?

YES ☐ NO ☐

If you answered YES, your associated swimming coach will be given copies of the summary sheets and will give them to you in person.

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

Signature                              Print name                              Date
Appendix 2: Ethics approval letter

Research Integrity
Human Research Ethics Committee

Thursday, 16 July 2015

Prof Ross Sanders
Exercise Health and Performance; Faculty of Health Sciences
Email: ross.sanders@sydney.edu.au

Dear Ross,

I am pleased to inform you that the University of Sydney Human Research Ethics Committee (HREC) has approved your project entitled "The effect of competition specific auditory stimulus training on swimming start reaction time".

Details of the approval are as follows:

Project No.: 2015/618
Approval Date: 15 July 2015
First Annual Report Due: 15 July 2016

Authorised Personnel: Sanders Ross; Formusek Che; Papic Christopher; Sinclair Peter;

Documents Approved:

<table>
<thead>
<tr>
<th>Date</th>
<th>Type</th>
<th>Document</th>
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<tbody>
<tr>
<td>15/07/2015</td>
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<td>Consent Form_Parent Carer_V3 150715</td>
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<td>Consent Form_Participant_V3 150715</td>
</tr>
<tr>
<td>09/07/2015</td>
<td>Participant info Statement</td>
<td>PIS - Elite Group</td>
</tr>
<tr>
<td>09/07/2015</td>
<td>Participant info Statement</td>
<td>PIS - Adolescent Group</td>
</tr>
<tr>
<td>28/05/2015</td>
<td>Questionnaires/Surveys</td>
<td>Survey (intervention group)</td>
</tr>
</tbody>
</table>

HREC approval is valid for four (4) years from the approval date stated in this letter and is granted pending the following conditions being met:

Condition/s of Approval:

- Continuing compliance with the National Statement on Ethical Conduct in Research Involving Humans.
- Provision of an annual report on this research to the Human Research Ethics Committee from the approval date and at the completion of the study. Failure to submit reports will result in withdrawal of ethics approval for the project.
- All serious and unexpected adverse events should be reported to the HREC within 72 hours.
- All unforeseen events that might affect continued ethical acceptability of the project should be reported to the HREC as soon as possible.

- Any changes to the project including changes to research personnel must be approved by the HREC before the research project can proceed.

- Note that for student research projects, a copy of this letter must be included in the candidate's thesis.

**Chief Investigator / Supervisor’s responsibilities:**

1. You must retain copies of all signed Consent Forms (if applicable) and provide these to the HREC on request.

2. It is your responsibility to provide a copy of this letter to any internal/external granting agencies if requested.

Please do not hesitate to contact Research Integrity (Human Ethics) should you require further information or clarification.

Yours sincerely

[Signature]

Professor Glen Davis  
Chair  
Human Research Ethics Committee

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This HREC is constituted and operates in accordance with the National Health and Medical Research Council’s (NHMRC) National Statement on Ethical Conduct in Human Research (2007), NHMRC and Universities Australia Australian Code for the Responsible Conduct of Research (2007) and the CPMP/ICH Note for Guidance on Good Clinical Practice.
Appendix 3: Swimming start data collection

Pre- and post-intervention dive testing: Reaction Time results

<table>
<thead>
<tr>
<th>Participant</th>
<th>Pre-intervention Reaction Time (s)</th>
<th>Post-intervention Reaction time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dive 1</td>
<td>Dive 2</td>
</tr>
<tr>
<td>C1P1</td>
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<td>C1P2</td>
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</table>

*Dive removed from participant mean result as RT < 0.1 s

**Technical error during data collection
## Pre- and post-intervention dive testing: Block Time results

<table>
<thead>
<tr>
<th>Participant</th>
<th>Pre-intervention Block Time (s)</th>
<th>Post-intervention Block Time (s)</th>
</tr>
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<tbody>
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<td></td>
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<td>0.697</td>
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* Dive removed from participant mean result as RT < 0.1 s

** Technical error during data collection
Pre- and post-intervention dive testing: ‘Time to 15m’ results

<table>
<thead>
<tr>
<th>Participant</th>
<th>Pre-intervention ‘Time to 15m’ (s)</th>
<th>Post-intervention ‘Time to 15m’ (s)</th>
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<tbody>
<tr>
<td></td>
<td>Dive 1</td>
<td>Dive 2</td>
</tr>
<tr>
<td>C1P1</td>
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</tr>
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<td>C1P2</td>
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<tr>
<td>C1P3</td>
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<tr>
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<td>C1P5</td>
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<tr>
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<td>7.16*</td>
<td>7.21</td>
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<tr>
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<tr>
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<tr>
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<tr>
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<td>**</td>
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</tr>
<tr>
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<td>C3P6</td>
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<td>6.57</td>
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</tbody>
</table>

* Dive removed from participant mean result as RT < 0.1 s

** Technical error during data collection

*** Participant had an upper limb injury and was unable to complete the swimming start phases beyond the ‘on-block’ phase at race pace