The Effects of Low-Volume, High-Intensity Training versus High-Volume, Low-Intensity Training on Performance in Competitive Swimmers, with a Specific Focus on Youth Swimmers

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A thesis submitted to the University of Limerick for the degree of Doctor of Philosophy

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Abstract

**Title:** The Effects of Low-Volume, High-Intensity Training versus High-Volume, Low-Intensity Training on Performance in Competitive Youth Swimmers.

**Author:** Frank Nugent

In recent years, the merits of low-volume, high-intensity training (HIT) programmes versus more traditional high-volume, low-intensity training (HVT) programmes has become a widely debated topic in competitive swimming. **Aim:** To investigate the effects HIT and HVT on performance in competitive swimmers. **Methods:** Study One involved a systematic review of the current literature to determine the effects of HIT on physiological and swimming performance in competitive swimmers. Study Two was a mixed methods study which explored expert swimming coaches’ perceptions of quality (i.e. HIT) and quantity (i.e. HVT) coaching philosophies. Study Three was an observational study which evaluated the effects of a 10 day period of HVT on competitive performance in youth swimmers. Study Four assessed the effects of a 7 week HIT intervention on performance parameters in competitive youth swimmers. **Results:** Study One identified 7 studies that were eligible for review. Six out of the 7 studies found HIT resulted in significant improvements in physiological performance. Four of the 7 studies found that HIT resulted in significant improvements in swimming performance. Study Two suggests expert swimming coaches felt quality programmes lead to short term results for youth swimmers however quantity programmes build an aerobic base, promote technical development and help to enhance recovery. Study Three found that competitive performance increased by 7.1% from pre-camp to post-camp ($p = 0.001, d_z = 1.6$). Study Four found that a 7 week HIT intervention was neither beneficial nor detrimental to performance parameters. **Conclusion:** Study One suggests the effects of HIT on performance are promising as the majority of studies either maintained or improved performance. However, the expert swimming coaches in Study Two advised against quality (i.e. HIT) programmes for youth swimmers. Study Three suggests that a 10 day period of HVT may improve competitive performance in youth swimmers. Study Four suggests that a 7 week HIT intervention was neither beneficial nor detrimental to performance parameters. Future studies should be $\geq 12$ weeks duration with larger sample sizes and should investigate the effect of HIT and HVT on similar performance parameters.
Declaration

I hereby declare that the work contained in this thesis is my own, and was completed without collaboration or assistance from others, other than the counsel of my supervisors, Dr. Giles Warrington and Dr. Thomas Comyns of the Department of Physical Education and Sport Sciences, University of Limerick.

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Frank Nugent

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Dr. Giles Warrington

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Dr. Thomas Comyns
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Glossary of Terms

**Biomechanics** – The application of the laws of mechanics to biological systems.

**Blood lactate** – A product of anaerobic metabolism and its measurement is used in physiological assessments of athletes.

**Determinants** – Factors that influence or determine performance.

**Dryland training** – Refers to any land based activities for swimmers such as strength training, flexibility sessions, games, etc.

**High-volume, low-intensity training (HIT)** – A training programme which focuses on performing low-intensity training (< 2 mM blood lactate) of longer duration.

**Low-volume, high-intensity training (HVT)** – A training programme which focuses on performing high-intensity training (> 4 mM blood lactate or > 87% of maximum heart rate) using repeated intervals.

**Maximal oxygen consumption (VO₂max)** – The highest rate of oxygen consumption attained during maximal or exhaustive exercise.

**Physiology** – The study of how living organisms function.

**Pubescent** – An individual at or approaching the age of puberty.

**Quality** – A swimming programme that focuses on lower volume training at high intensities.

**Quantity** – A swimming programme that focuses on higher volume training at low intensities.

**Velocity** – the speed of something in a given direction.

**Youth** – Represents the period from 2 to 18 years of age in both males and females.
List of Abbreviations

AMPK – AMP-activated protein kinase
ANOVA – Analysis of variance
ANS – Autonomic nervous system
AOD – Accumulated oxygen deficit
ATP – Adenosine triphosphate
ATP-CP – Adenosine triphosphate and phosphocreatine
AU – Arbitrary units
BLa_peak – Peak blood lactate accumulation
BLa_submax – Sub-maximal lactate indices
BBM – Heart beats below maximum
Ca^{2+} – Calcium concentration
CaMK – Calcium-calmodulin kinases
cm – Centimetre
CP – Competitive performance
CV – Coefficient of variation
C_{velocity} – Critical velocity
d_z – Cohen’s effect size
ETL – External training load
F – Female
F_d – Resistive or drag forces
F_p – Propulsive forces
FPS – FINA points system
GAS – General adaptation syndrome
GLUT4 – Glucose transporter 4
HIT – Low-volume, high-intensity training
HR – Heart rate
HR_{max} – Maximal heart rate
HVT – High-volume, low-intensity training
IAT – Individual anaerobic threshold
ICC – Intra class correlation
IQR – Interquartile ranges
IRP – Individualised race pace
IST – Incremental swimming test
ITL – Internal training load
kg – Kilogram
km – Kilometres
L/min – Litres per minute
La^{-} – Blood lactate concentration
LIT – Low-intensity training
LSD – Long slow distance training
LT_{1} – Aerobic threshold
LT_{2} – Anaerobic threshold
LTAD – Long-term athlete development
M – Male
m – Metre
m/s – Metres per second
m/stroke – Metres travelled per swimming stroke
Mdn – Median
MIT – Moderate-intensity training
MLSS – Maximal lactate steady state

mM – Millimols

n – Number

OT – Overtraining Syndrome

P – Performance

PGC-1α – Peroxisome proliferator-activated receptor-γ coactivator-1α

PHV – Peak height velocity

PRISMA-P – Preferred reporting items for systematic review and meta-analysis document

PROSPERO – International prospective register of systematic reviews

QI – Quality index checklist

r – Pearson’s correlation coefficient

RPE – Rating of perceived exertion

r_s – Spearman’s rank correlation coefficient

s – Second

SD – Standard deviation

SI – Stroke index

SL – Stroke length

SR – Stroke rate

Strokes/min – Swimming stroke per minute

SV – Swimming velocity

T – Time

TA – Turn around

TTP – Maximal time trial performance

TV – Training volume
USRPT – Ultra-short race-pace training

$\dot{V}O_{2\text{max}}$ – Maximal oxygen uptake

$\dot{V}O_{2\text{peak}}$ – Peak oxygen consumption

$VT_1$ – First ventilatory threshold

$VT_2$ – Second ventilatory threshold

$X^2$ – Chi-squared test

YPD – Youth physical development model

$\eta_p^2$ – Partial eta squared
Chapter 1: Introduction
1.1 Background and Justification

The sport of swimming has been part of the Olympic programme since the establishment of the first modern Olympic Games in 1896. Over this time swimming has progressed to become one of the largest Olympic sports with 34 events ranging in distance from 50 to 10,000 m. The Gold Medal winning times at the Rio 2016 Olympics ranged in duration from 21.4 seconds for the 50 m event to approximately 1 hour 56 minutes 32.1 seconds for the 10,000 m event. However twenty-six out of thirty-four (76%) Olympic level swimming events are competed over a race distance of 200 m or less, for a typical duration of less than 2 minutes 20 seconds.

Despite the relatively short duration of the majority of swimming events, the training practices of swimmers typically involve high training volumes (i.e. the total training distance or duration completed per session, week, month, etc.). This is a common training practice across all age cohorts and swimming events (Maglischo 2003a, Sweetenham and Atkinson 2003). Furthermore, the training volume of competitive swimmers is typically well in excess of other cyclical sports such as running, rowing, cross country skiing and cycling (Seiler and Tønnessen 2009). This is particularly evident at youth level where mean swimming training volumes of 16 hours per week are common (Faude et al. 2008, Sein et al. 2010, Hibberd and Myers 2013) and in some cases may range up to 29 hours (or 110 km) per week (Sein et al. 2010). Perhaps due to the specialized nature of swimming training, it is not uncommon for elite swimmers to achieve World and Olympic success at a relatively young age. For example, the Lithuanian Rūta Meilutytė won the Gold medal at the London 2012 Olympics in the 100 m breaststroke at 15 years of age. At the same Olympics, the American Katie Ledecky won the Gold medal in the 800 m freestyle also when 15 years old.

The training volume of competitive swimmers is most commonly completed in the format of high-volume, low-intensity training (HVT) which is defined as a training programme which focuses on performing low-intensity training (< 2 mM blood lactate) of longer duration, also referred to as long slow distance (LSD) training or “zone 1” training (Stoggl and Sperlich 2015). An expert commentary article by Greyson et al. (2010) suggest that HVT programmes for competitive swimmers are vital in order to develop efficient swimming technique, to build the aerobic energy system and to target the optimal window for aerobic development as proposed in the Long-Term Athlete
Development (LTAD) model (Balyi and Hamilton 2004). The relevance of HVT to the physiological and biomechanical requirements of many swimming events has long been questioned in the scientific literature (Costill et al. 1991, Lang and Light 2010, Aspenes and Karlsen 2012) as 76% of Olympic level events are competed over less than 2 minutes 20 seconds. In addition, HVT has been linked to an increased risk of shoulder injury (Sein et al. 2010, Madsen et al. 2011), overtraining syndrome (Hooper et al. 1993, Raglin et al. 2000) and early specialisation (Moesch et al. 2011, Jayanthi et al. 2013, Myer et al. 2015a) in competitive swimmers. The relevance of HVT is also a long standing topic of discussion among swimming coaches (Stott 2012a, Salo 2015, Goldsmith 2016), and has been referred to as the “Quality versus Quantity debate” (Maglischo 2003b, Salo and Riewald 2008b). On the quality side of the debate there is the suggestion that the focus of the swimming programme should be on lower volume training at high intensities, whereas the quantity side suggest that higher volume training at low intensities will enhance swimming performance (Maglischo 2003b, Salo and Riewald 2008b).

A quality or low-volume, high-intensity training (HIT) programme is defined as a training programme which focuses on performing high-intensity training (> 4 mM blood lactate or > 87% of maximum heart rate) using repeated intervals, also referred to as “zone 3” training (Stoggl and Sperlich 2015). In recent years, HIT has become a training methodology that is receiving an increasing amount of investigation as it may allow for a reduction in overall training volume, through an increase in training intensity (Laursen and Jenkins 2002). A reduction in training volume through implementing a HIT programme could potentially be of benefit to competitive swimmers who may have limited training time due to school/university timetables, exam periods or participation in multiple sporting activities. In addition, a HIT programme may be more specific to the physiological and biomechanical demands of the majority of swimming events. The earliest research on this topic was conducted by David Costill and colleagues (Costill et al. 1991) nearly thirty years ago and despite subsequent studies (Faude et al. 2008, Sperlich et al. 2010, Kilen et al. 2014), few definitive conclusions have been reached. Therefore, the effects of HIT and HVT (i.e. Quality versus Quantity) in competitive swimming require further research.
1.2 Research Aims

The aim of this thesis was to investigate the effects of HIT and HVT on performance in competitive swimmers. The specific objectives were as follows:

- To conduct a systematic review examining the extent and quality of the current research literature in order to determine the effects of HIT on physiological performance and swimming performance in competitive swimmers (Study 1, Chapter 3).
- To explore expert swimming coaches’ perceptions of quality and quantity coaching philosophies in competitive swimming and to investigate their current training practices (Study 2, Chapter 4).
- To investigate the effects of increased training volume during a 10 day training camp on competitive performance, internal training load (ITL) and coach-swimmer rating of perceived exertion (RPE) in competitive youth swimmers (Study 3, Chapter 5).
- To assess the effects of a 7 week HIT intervention on performance parameters in competitive youth swimmers (Study 4, Chapter 6).

1.3 Thesis Structure

This thesis consists of seven chapters. Chapter 2 provides a short literature review of the physiological and biomechanical demands of swimming, the training requirements of the youth athlete are discussed and the applications, adaptations and underlying mechanisms of HVT and HIT are provided. Chapters 3, 4, 5 and 6 are four independent, but inter-related studies. These chapters are all presented in the structure of a journal article with an introduction, methods, results, discussion and conclusion section. Chapter 3 and 4 are published in peer-reviewed journals while Chapter 5 and 6 are in press (Table 1.1). Minor formatting and changes to the articles have been made in order to aid presentation and readability of this thesis. Chapter 7 provides the thesis summary, conclusions and recommendations.
Table 1.1 Journal of publication, ISI impact factor and quartile for each chapter presented in this thesis.

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Journal</th>
<th>Impact Factor</th>
<th>Quartile</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>The Journal of Strength and Conditioning Research</td>
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<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Journal of Human Kinetics</td>
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<td>4</td>
</tr>
<tr>
<td>5</td>
<td>The Journal of Sports Medicine and Physical Fitness</td>
<td>1.120</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>International Journal of Sports Physiology and Performance</td>
<td>3.384</td>
<td>1</td>
</tr>
<tr>
<td>Appendix 4</td>
<td>Strength and Conditioning Journal</td>
<td>0.651</td>
<td>4</td>
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</tbody>
</table>
Chapter 2: Literature Review
2.1 Introduction to Swimming

Swimming is a cyclical and non-weight bearing sport where individual swimmers or teams of swimmers (i.e. relay events) compete against each other over various distances and swimming strokes. A cyclical sport is defined as a motor action that involves repetitive movements such as rowing, running, kayaking and cycling (Bompa and Haff 2009). Swimming is one of the few sports where athletes frequently compete in numerous events that differ in both distance and stroke technique. This is particularly evident at youth level where swimmers are often trained to compete across multiple events in order to increase their range of opportunities in competition.

Michael Phelps is a prime example of a swimmer that was trained from an early age to compete across numerous events. This accumulated in him becoming the most successful Olympian of all time and winner of 28 Olympic medals (23 Gold) in 100, 200 and 400 m events across four different swimming stroke techniques. The four swimming stroke techniques are freestyle, backstroke, butterfly and breaststroke. There are also medley events where a swimmer completes all four strokes during the race. The events are typically divided into sprint (50 and 100 m), middle distance (200 and 400 m) and long distance (800, 1,500 and 10,000 m) categories (Maglischo 2003e).

The majority of swimming events can be broken down into three main components – the start from blocks, the turn (s) off the wall and the swim itself with each stroke technique having specific technical requirements. The variety of swimming stroke techniques, event distances and individual components make swimming a complex and demanding sport from a physical, technical and tactical standpoint. Table 2.1 provides a summary of the Gold Medal winning times for the 34 swimming events at the Rio 2016 Olympics. However it can be expected that at youth level these times would be much slower.
Table 2.1 Gold Medal winning times at the Rio 2016 Olympics (*Rio: Swimming* 2016)

<table>
<thead>
<tr>
<th>Event</th>
<th>Distance</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freestyle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>50 m</td>
<td>21.40</td>
<td>24.07</td>
</tr>
<tr>
<td></td>
<td>100 m</td>
<td>47.58</td>
<td>52.70</td>
</tr>
<tr>
<td></td>
<td>200 m</td>
<td>1:44.65</td>
<td>1:53.73</td>
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<tr>
<td></td>
<td>400 m</td>
<td>3:41.55</td>
<td>3:56.46</td>
</tr>
<tr>
<td></td>
<td>800 m</td>
<td>---------</td>
<td>8:04.79</td>
</tr>
<tr>
<td></td>
<td>1500 m</td>
<td>14:34.57</td>
<td>---------</td>
</tr>
<tr>
<td></td>
<td>10,000 m</td>
<td>1:52:59.8</td>
<td>1:56:32.1</td>
</tr>
<tr>
<td>Backstroke</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>100 m</td>
<td>51.97</td>
<td>58.45</td>
</tr>
<tr>
<td></td>
<td>200 m</td>
<td>1:53.62</td>
<td>2:05.99</td>
</tr>
<tr>
<td>Breaststroke</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>100 m</td>
<td>57.13</td>
<td>1:04.93</td>
</tr>
<tr>
<td></td>
<td>200 m</td>
<td>2:07.46</td>
<td>2:20.30</td>
</tr>
<tr>
<td>Butterfly</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>100 m</td>
<td>50.39</td>
<td>55.48</td>
</tr>
<tr>
<td></td>
<td>200 m</td>
<td>1:53.36</td>
<td>2:04.85</td>
</tr>
<tr>
<td>Individual Medley</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>200 m</td>
<td>1:54.66</td>
<td>2:06.58</td>
</tr>
<tr>
<td></td>
<td>400 m</td>
<td>4:06.05</td>
<td>4:26.36</td>
</tr>
<tr>
<td>Freestyle Relay</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 × 100 m</td>
<td>3:09.92a</td>
<td>3:30.65d</td>
</tr>
<tr>
<td></td>
<td>4 × 200 m</td>
<td>7:00.66b</td>
<td>7:43.03e</td>
</tr>
<tr>
<td>Medley Relay</td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>4 × 100 m</td>
<td>3:27.95c</td>
<td>3:53.13f</td>
</tr>
</tbody>
</table>

*Individual 100 m freestyle relay times of 46.97 – 48.10
46.97 – 53.74
1:44.14 – 1:46.03
1:46.34 – 1:56.69
1:46.43 – 1:56.70
1:46.74 – 59.03

2.2 The Physiological Demands of Swimming

The physiological demands of the events in Table 2.1 involve varying contributions of the alactic-anaerobic, lactic-anaerobic and aerobic energy system with the specific contributions depending on the distance and duration of the event (Pyne and Sharp 2014). However, quantifying the specific energy system contributions to each swimming event is challenging due to the large variety of competitive distances and stroke techniques. In addition there are methodological difficulties surrounding physiological testing in aquatic sports such as the difficulties associated with recording maximal oxygen uptake ($\dot{V}O_2$max) and heart rate underwater.

A review article by Gastin (2001), of the energy system contributions during maximal exercise concluded that aerobic energy supply dominates the total energy requirements
after about 75 seconds of maximal effort in cyclical events. The majority of reviewed studies were performed using trained runners and cyclists who completed various durations of maximal effort exercise in order to establish the contributions of each energy system, primarily by measuring the accumulated oxygen deficit (AOD). The AOD is used as a measure of anaerobic capacity and is determined by the relationship between submaximal work intensities and oxygen consumption, which is used to predict supramaximal energy demand (Gastin 2001). The findings of Gastin (2001) are in agreement with a series of studies by Duffield and colleagues (Duffield et al. 2004, Duffield et al. 2005a, Duffield et al. 2005b) on trained runners and a review by Laursen (2010).

In swimming, the 200 m event has a typical duration of around 2 minutes, depending on the specific cohort and stroke technique, therefore the findings of Gastin (2001) would suggest that 200 m events and above should be more dependent on aerobic energy supply. A number of studies have investigated the energy system contributions to 200 m swimming events in youth swimmers (Zamparo et al. 2000) and elite senior swimmers (Capelli et al. 1998, Figueiredo et al. 2011). The energy system contributions were estimated using equations that included measurements of $\dot{V}O_{2\text{max}}$ and peak blood lactate concentration ($BLa_{\text{peak}}$) during swimming. The findings of these studies suggest that 200 m swimming events involve an aerobic energy contribution of 71.1% in youth swimmers (aged 14.5 ± 1.9 years) and between 63 – 65.9% in elite senior swimmers. Therefore, swimming events less than 200 m (50 and 100 m) appear to be more dependent on alactic-anaerobic and lactic-anaerobic energy supply, as they are < 75 seconds duration, while events of 200 m and above (200, 400, 800, 1,500 and 10,000 m) are more dependent on aerobic energy supply.

A number of studies have investigated the physiological determinants of swimming performance in youth swimmers (Jürimäe et al. 2007, Lätt et al. 2010). The most commonly utilised physiological parameters in these studies were peak oxygen consumption ($\dot{V}O_{2\text{peak}}$), $BLa_{\text{peak}}$ and critical velocity ($C_{\text{velocity}}$). Peak oxygen consumption is defined as the highest oxygen consumption elicited during an exercise test to exhaustion and is a popular index of aerobic fitness across many sports (Armstrong and Welsman 1994). In swimming, $\dot{V}O_{2\text{peak}}$ is generally measured over a maximal effort time trial or incremental test using either a respiratory snorkel connected to a portable gas analyser (Lätt et al. 2010) or immediately post-swim using the
backward extrapolation technique which involves collecting expired gases from the swimmer using either a portable gas analyser or Douglas bag during the first 20 seconds of post-swim recovery (Jürimäe et al. 2007). Peak blood lactate concentration is defined as the accumulated or peak blood lactate value, which is measured at defined time points post-exercise, and has been used as an indicator of anaerobic capacity (Gastin 1994). Critical velocity is defined as the highest velocity which can be maintained without exhaustion and is considered an indicator of aerobic capacity (Wakayoshi et al. 1992). Critical velocity is calculated as the slope of the regression line of the distance-time plot established between a minimum of two swimming distances (e.g. 200 and 800 m) (Wakayoshi et al. 1992). However, an easier method of estimating $C_{velocity}$ was recently established using one 400 m maximal effort time trial (Zacca et al. 2016).

Lätt et al. (2010) investigated the physiological determinants of 100 m performance in 25 youth swimmers (15.2 ± 1.9 years) and found $\dot{V}O_{2peak}$, measured during swimming, and $BL_{peak}$ determined 45.2% of performance. A similar study by Jürimäe et al. (2007) found $\dot{V}O_{2peak}$, measured immediately post-swim, determined 35.8% of 400 m performance in 15 pre-pubertal swimmers (11.9 ± 0.3 years) and 14 post-pubertal swimmers (14.3 ± 1.4 years). This is an unusual finding as longer duration swimming events such as the 400 m typically involve a greater aerobic energy demand and thus it would be expected that $\dot{V}O_{2peak}$, would be a stronger determinant of performance compared to 200 m. Similarly, De Mello Vitor and Böhme (2010) found $C_{velocity}$, an indicator of aerobic capacity, determined only 34% of 100 m performance in 24 youth swimmers (13.0 ± 0.7 years). Commonly utilised physiological parameters such as $\dot{V}O_{2peak}$, $BL_{peak}$ and $C_{velocity}$ do not appear to be strong determinants of swimming performance however biomechanical measures are consistently found to be one of the strongest determinants of swimming performance (Jürimäe et al. 2007, De Mello Vitor and Böhme 2010, Lätt et al. 2010, Mezzaroba and Machado 2014).

2.3 The Biomechanical Demands of Swimming
In land-based sports, force is applied against the ground in order to accelerate forwards whereas in swimming, force is applied against the water. Swimmers can therefore propel their body forward by pushing their limbs backwards against the resistance of the water, similar to a runner accelerating forwards by pushing backwards against the ground (Maglisco 2003d). However as water is a fluid, it gives way when limbs push
against it while the ground, for a runner, does not. This may be a contributing factor towards the traditional HVT approach in swimming as increasing the overall practice or training time could potentially create increased opportunities to improve the complex skill of applying force against a fluid medium, which coaches commonly refer to as “feel” for the water (Toussaint and Beek 1992).

Swimming performance is dependent on the ability of a swimmer to maximize propulsion through the water while reducing resistance to forward motion (Pyne and Sharp 2014). Propulsion occurs as a result of the propulsive forces ($F_p$) generated by the arms and legs during the swimming stroke which results in forward motion, as seen in Figure 2.1 (Toussaint & Beek, 1992). Resistance occurs as a result of the resistive or drag forces ($F_d$) a swimmer experiences during forward motion as water has a significantly greater density than air (Pyne & Sharp, 2014). Resistive or drag forces act in the opposite direction to propulsive forces, see Figure 2.1 (Toussaint and Beek 1992).

![Figure 2.1](image)

**Figure 2.1** – Swimming performance is dependent on the ability to maximise propulsive forces ($F_p$) while reducing resistive or drag forces ($F_d$) during forward motion (Toussaint & Beek, 1992).

There are three main components of resistance or drag that act on a swimmer as they move through the water: frictional drag (the resistance created between the water and the swimmer’s skin), form drag (the resistance created by the profile of the swimmer in the water) and wave drag (the resistance created by waves when swimming at or near the surface) (Maglischo 2003c, Tor et al. 2015). In order for a swimmer to accelerate they must generate a rate of work per stroke that equals the power necessary to overcome resistance from the water (Barbosa et al. 2010a). A swimmer will attain their maximum velocity when they fail to produce $F_p$ that exceeds the $F_d$ acting on them (Toussaint and Beek 1992, Barbosa et al. 2010a). This highlights the reason why swimming performance is highly dependent on a swimmer’s biomechanical or technical
skill in generating $F_p$ while reducing $F_d$, which is directly linked to the physiological demands (Toussaint and Beek 1992, Barbosa et al. 2010a, Pyne and Sharp 2014).

Biomechanical parameters such as stroke rate (SR), stroke length (SL) and stroke index (SI) have been consistently found to be among the best determinants of swimming performance in youth swimmers (Jürimäe et al. 2007, Lätt et al. 2010, Mezzaroba and Machado 2014). Stroke rate is defined as the number of swimming stroke cycles performed per minute and is calculated by timing three stroke cycles using a manual chronometer (Smith et al. 2002). Stroke length is defined as the distance the swimmer travels per stroke cycle and is calculated by dividing swimming velocity (SV) by SR (Smith et al. 2002). Stroke index was first defined by Costill et al. (1985) as the swimmer’s stroke efficiency and is calculated by multiplying SV by SL. Lätt et al. (2010) found SR, SL and SI determined 90.3% of 100 m freestyle performance in 25 competitive youth swimmers (15.2 ± 1.9 years). A study by Jürimäe et al. (2007) found SR, SL and SI determined 89.8% of 400 m freestyle performance in 15 pre-pubertal swimmers (11.9 ± 0.3 years) and 14 post-pubertal swimmers (14.3 ± 1.4 years). Mezzaroba and Machado (2014) reported similar findings in a larger cohort of 46 youth swimmers ranging in age from 10 – 17 years old. SR, SL and SI were found to determine 97 – 99% of 100 m, 200 m and 400 m performance. Interestingly, SI alone determined 87 – 90% of 100 m, 200 m and 400 m performance. Despite many of these studies being conducted on youth swimmers, biomechanical parameters such as SL and SI have been shown to be higher in senior swimmers when compared to lower calibre swimmers (Sánchez and Arellano 2002, Smith et al. 2002).

2.4 Training the Youth Athlete

2.4.1 Physical and Physiological Development of the Youth Athlete

In order to fully understand the training practices of youth swimmers, one must first understand the physical and physiological changes that occur in the youth athlete across maturation. The term “maturation” is defined as the tempo and timing of progress towards a mature biological state (Malina et al. 2004). There are a number of distinct phases of maturation – prenatal, childhood, adolescence and adulthood (Van Praagh and Doré 2002). For the purposes of this thesis, the childhood and adolescent phases are of primary interest. The childhood phase represents the period from 2 to 12 years of age while the adolescent phase represents the period from 12 to 18 years of age (Van Praagh
and Doré 2002). It is during the adolescent phase that puberty occurs which results in a number of profound changes within the body such as increased height and body mass, the appearance of secondary sex characteristics and the ability to reproduce (Van Praagh and Doré 2002). However, the tempo and timing of maturation can vary considerably between individuals of the same chronological age (Mirwald et al. 2002). Therefore, it is important to determine maturity status when conducting research on youth athletes.

Maturity status is commonly measured using assessments of skeletal age and secondary sex characteristics (Tanner and Whitehouse 1976, Malina et al. 2004). However, assessments of skeletal age such as hand-wrist radiographs are not generally accessible to the majority of applied sports science practitioners while assessments of secondary sex characteristics, such as pubic hair, can be invasive. A non-invasive and practical method of predicting years from peak height velocity (PHV), using a predictive equation, has been developed by Mirwald et al. (2002). The term “PHV” is defined as the point during maturation when the rate of growth in height is at its maximum which is calculated using simple anthropometrical measures (Mirwald et al. 2002). The Mirwald et al. (2002) equation has been widely adopted in paediatric research (Sherar 2007, Mohamed 2009, Lloyd 2011, Lloyd 2012) however there are limitations to this method such as increases in accuracy as participants approach PHV and reductions in accuracy the further the participant is away from their PHV (Gunter et al. 2008).

The physiological responses of a youth athlete to an acute bout of exercise may differ according to their age and stage of maturation (Gamble 2014). A review article by Boisseau and Delamarche (2000), suggests that the anaerobic energy system is less well developed in pre-pubescent athletes for a number of reasons. Prior to puberty, a greater proportion of slow twitch (type-I) fibres are evident in the lower-limb muscles relative to adults, whereas this difference was not observed in post-pubescent athletes (Boisseau and Delamarche 2000). In addition, the reduced activity of anaerobic enzymes and limited production of muscle lactate relative to adults could also explain the lower anaerobic capacity of pre-pubescent athletes compared to post-pubescent athletes and adults. Boisseau and Delamarche (2000) suggests that energy metabolism in pre-pubescent athletes is fuelled to a greater extent by fat oxidation than in adults. Prior to puberty, lower respiratory exchange ratio values are often observed during prolonged exercise. In addition, increased free fatty acid mobilisation, glycerol release and growth hormone further support the notion that pre-pubescent athletes rely more on fat
oxidation than adults. The findings of Boisseau and Delamarche (2000) are in agreement with more recent studies which also suggest that pre-pubescent athletes have a less well developed anaerobic energy system than adults and rely more on aerobic metabolism (Ratel and Blazevich 2017, Birat 2018).

These observations have led some authors to suggest that anaerobic exercise should be limited in pre-pubescent athletes and a greater focus should be placed on aerobic exercise (Boisseau and Delamarche 2000, Naughton 2000, Balyi and Hamilton 2004). However, more recent data examining the training responses of pre-pubescent athletes to anaerobic training (e.g. HIT) challenges this assertion (McManus 2005, Baquet 2010, Sperlich et al. 2011). For example, a study by Sperlich et al. (2011) investigated the effects of HIT on performance in pre-pubescent swimmers and reported significant improvements in performance over sprint (50 and 100 m) and long distance (2,000 m) swimming events, \( \dot{V}O_2^{\text{peak}} \) and BLa\(^{\text{peak}} \). The 20.1% increase in BLa\(^{\text{peak}} \) are in contrast to the findings of the review by Boisseau and Delamarche (2000) who suggest pre-pubescent athletes have limited muscle lactate production. Therefore, HIT appears to be an effective training stimulus for pre-pubescent athletes (McManus 2005, Baquet 2010, Sperlich et al. 2011).

Similarly, pubescent and post-pubescent athletes have been found to benefit from HIT interventions (Faude et al. 2008, Sperlich et al. 2011, Faude et al. 2013). It is common knowledge that youths frequently engage in free play that could be characterized as repeated sprint activity or HIT (e.g. chasing games in the playground) and perhaps high intensity activities could be a more natural training method for youths. In addition, pre-pubescent athletes have been shown to have a greater resistance to fatigue and greater recovery abilities during high intensity exercise (Hebestreit et al. 1993, Falk and Dotan 2006, Ratel and Blazevich 2017). This may be due to a number of factors such as greater cardiorespiratory recovery kinetics, enhanced aerobic metabolism, different motor-unit recruitment, and lower production and/or more efficient removal of metabolic by-products (i.e. blood lactate) than adults (Falk and Dotan 2006, Ratel et al. 2006). Therefore, HIT interventions may be highly appropriate and specific to the physiology of the youth athlete, particularly pre-pubescent athletes.
2.4.2 Challenges to Health and Well-Being for the Youth Athlete

The health, fitness and well-being of modern day youth is a rapidly increasing topic of interest at the moment due to major concerns surrounding physical inactivity, childhood obesity and its association with the development of chronic diseases such as cardiovascular disease and diabetes (Dietz 1998, Inge et al. 2013). Therefore, keeping youths involved in sport is of utmost importance however, this is not without a number of distinct challenges. In swimming, the commonly high training volumes at youth level can lead to early sport specialisation (Myer et al. 2015b), overuse injury (Sein et al. 2010, Hibberd and Myers 2013, Post et al. 2017) and overtraining syndrome (Raglin et al. 2000, Matos et al. 2011). Early sport specialisation is defined as intensive year-round training in a single sport at the exclusion of other sports (Jayanthi et al. 2013). The three criteria that define early sport specialisation in youths include 1) participation in year-round training (> 8 months per year), 2) choosing a single main sport and 3) quitting all other sports to focus on one main sport (Jayanthi et al. 2015). Anecdotally, it is very common for youth swimmers to meet all three criteria and perhaps it is no surprise that swimmers as young as 14 years old have won the Olympic Gold medal (e.g. Kyoko Iwasaki, Japan, 200 m breaststroke, Barcelona Olympics 1992). Early sport specialisation is also common in other sports such as gymnastics, diving and figure skating (Myer et al. 2015b).

Achieving a high level of swimming success at an early age is not an unusual occurrence and it is common for a talented youth swimmer to be much faster than their more mature and senior level peers. This is perhaps due to swimming performance being strongly dependent on the biomechanical profile adopted by the swimmer (Toussaint and Beek 1992, Barbosa et al. 2010a). Therefore, a highly skilled youth swimmer producing high propulsive forces and low resistive or drag forces (due to a smaller body shape) can swim at higher velocities than a senior swimmer producing the same propulsive forces but with higher resistive or drag forces (due to a larger body shape) (see 2.3 The biomechanical demands of swimming). This places distinct logistical demands upon swim coaches due to the often limited lane space availability in public swimming pools (i.e. the talented youth swimmer will be too fast to swim in a lane with their peers). Consequently, talented youth swimmers are often rapidly progressed to senior teams where training volume and training frequency are much higher, thus specialising early. Research suggests that youths should avoid early sport specialisation as regular participation in multiple sports enhances motor skill
development, improves athletic capacity and increases the opportunity for a youth to discover the sport(s) that he/she enjoys and can possibly excel at (Jayanthi et al. 2013, Mostafavifar et al. 2013).

In addition, early sport specialisation is associated with an increased risk of injury in youth athletes (Jayanthi et al. 2015, Myer et al. 2015a, Post et al. 2017). A study by Post et al. (2017) investigated the association between sports specialisation and injury history in 2011 competitive youth athletes (13.7 ± 1.6 years) across 18 different sports. The results indicated that highly specialised athletes were more likely to report an overuse injury (p = 0.01) compared with less specialised athletes. Athletes who played a main sport more than 8 months of the year were more likely to report an upper extremity overuse injury (p = 0.04) or lower extremity overuse injury (p = 0.001). Athletes who participated in their primary sport for more hours per week than their age were more likely to report an injury of any type (p = 0.001).

In swimming, the repetitive and overhead nature of the sport means that athletes are often at a greater risk of injury, particularly when high volumes of specialised training and competition are undertaken at an early age (Sein et al. 2010, Hibberd and Myers 2013). Sein et al. (2010) investigated the association between training practices and shoulder impingement in 86 competitive youth swimmers (15.9 ± 2.7 years) who had a median swim training volume of 16 hours or 40 km per week. Sein et al. (2010) found a significant correlation between the presence of shoulder impingement and both the number of hours swum per week (r_s = 0.39, p < 0.005) and the numbers of kilometres (km) completed per week (r_s = 0.34, p = 0.01). Hibberd and Myers (2013) investigated the attitudes and behaviours towards shoulder pain in 102 competitive youth swimmers (15.1 ± 1.4 years) who had a mean swim training volume of around 41 km per week. Seventy-two percent (73/102) of the swimmers reported using pain medication in the past year to manage their shoulder pain so that they could participate in training. A significant relationship was found between the attitude that severe shoulder pain is normal and the behaviour of swimming with severe shoulder pain (X^2(85) = 0.552, p < 0.0005). Hibberd and Myers (2013) concluded that competitive youth swimmers believe that shoulder pain is normal and should be tolerated in order to complete the required training volume.
The increased pressures of specialized training and competition may also lead to overtraining syndrome (OT) (Myer et al. 2015a). Overtraining syndrome is defined as an accumulation of training and non-training stressors that results in decreased ability to perform at established levels, which may persist for several weeks to months (Budgett 1998, Kreider et al. 1998). Common symptoms of OT include mood disturbances (Morgan et al. 1987); increased perceptions of effort with training and competition (Kenttä and Hassmén 1998); loss of appetite; sleep disturbances and increased incidences of upper respiratory tract infections (Fry et al. 1991). A study by Matos et al. (2011) investigated the prevalence of OT in 376 youth athletes (15.1 ± 2.0 years) across 19 different individual and team sports. One hundred ten youth athletes (29%) reported having OT at least once in their sporting career. The incidence of OT was significantly higher in individual sports (i.e. swimming, diving, golf, etc.) (p < 0.01) and at a higher competitive level (i.e. national and international level competitors) (p < 0.01). A study by Raglin et al. (2000) investigated the prevalence of OT in 231 youth swimmers (14.8 ± 1.4 years) across four different countries. Of the total sample, eighty (34.6%) youth swimmers indicated that they had developed OT during their swimming career and the mean number of OT episodes was 2.7 ± 1.4. The majority of OT (75%) was reported to occur during the hardest periods of training. The swimmers with OT had faster 100 m personal best times than the swimmers without OT (p < 0.01), therefore the swimmers with OT were of a higher competitive level. Therefore, youth athletes in individual sports, such as swimming, who compete at a high level and generally complete more specialised training at an early age, appear to be at a greater risk of OT. This could potentially lead to psychological burnout and early dropout from sport, particularly in youth swimmers (Monteiro et al. 2018).

Faigenbaum and Meadors (2017) suggest a more holistic approach should be taken to develop youth athletes. Training programmes should encompass a wide range of opportunities such as building strength, developing movement skill competency, fostering creativity and increasing enjoyment through games and free play (Faigenbaum and Meadors 2017). However, in the current climate it is logistically difficult to understand how these opportunities for holistic athletic development can be created for youth swimmers when the current swimming training volumes for this cohort are consistently in excess of 16 hours per week (Faude et al. 2008, Sein et al. 2010, Hibberd and Myers 2013). Consequently, issues relating to health and well-being such as early sport specialization (Jayanthi et al. 2013, Myer et al. 2015a); overuse injuries
(Sein et al. 2010, Hibberd and Myers 2013); overtraining syndrome (Raglin et al. 2000, Post et al. 2017) and early dropout (Monteiro et al. 2018) are common in this cohort. Therefore, any potential methods of decreasing the current training volume of swimmers (e.g. HIT) in order to incorporate these holistic elements into a swimming training programme should be evaluated.

2.4.3 Youth Development Models

The evident shift towards holistic development focusing on increasing the health and well-being of youths participating in sport has resulted in the publication of numerous guidelines that detail long-term models of youth development which aim to increase both physical activity levels and sporting success in youth (Gagne 1993, Balyi and Hamilton 2004, Bailey and Morley 2006, Cote et al. 2007, Lloyd and Oliver 2012). The Long-Term Athlete Development (LTAD) model, as first proposed by the Canadian sports scientist Istvan Balyi in the late 1990’s is a widely utilised model that has been adopted by numerous sporting organisations worldwide (Balyi et al. 2013). The LTAD model aims to align training prescription with the timing of maturation as opposed to chronological age which may help to better individualise training programmes for youths (Balyi and Hamilton 2004). The LTAD model suggests that training prescriptions should be tailored based on the individual’s stage of maturation in order to take advantage of the “windows of opportunity” for developing specific athletic components such as motor skills, speed, aerobic capacity and strength (Balyi and Hamilton 2004). The “windows of opportunity” are suggested to be sensitive periods during maturation where training-induced adaptations may be accelerated for each athletic component (Ford et al. 2011).

The LTAD model has seven distinct stages: 1) Active Start (males and females 0 – 6 years); 2) FUNdamentals (males 6 – 9 years and females 6 – 8 years); 3) Learning to Train (males 9 – 12 years and females 8 – 11 years); 4) Training to Train (males 12 – 16 years and females 11 – 15 years); 5) Training to Compete (males 16 – 18 years and females 15 – 17 years); 6) Training to Win (males 18+ years and females 17+ years); and 7) Active for Life (enter at any age) (Balyi et al. 2013). This model has been adapted numerous times to suit the specific requirements of various sports and thus the chronological age ranges and stages may differ slightly (Balyi et al. 2013). In swimming, an adapted LTAD model has been heavily criticised (Arrellano 2010, Lang and Light 2010, Treffene 2010). A study by Lang and Light (2010) investigated the
interpretation and implementation of an adapted LTAD model called “The Swimmer Pathway”, which was first introduced in 2003 by the Amateur Swimming Association (ASA) in the United Kingdom. Lang and Light (2010), interviewed six elite and five non-elite English swimming coaches and the main concern expressed by the swimming coaches was that The Swimmer Pathway overemphasised training volume leading to the neglect of technique. The training volumes recommendations of The Swimmer Pathway are provided in Table 2.2.

Table 2.2 The training recommendations of a swimming-specific LTAD model – The Swimmer Pathway (Lang and Light 2010)

<table>
<thead>
<tr>
<th>Chronological/biological age</th>
<th>FUNdamental</th>
<th>SwimSkills</th>
<th>Training to Train</th>
<th>Training to Compete</th>
<th>Training to Win</th>
</tr>
</thead>
</table>

Recommended number of sessions per week
- 5 – 6 general sports
- 4 – 6 swim-specific, plus additional participation in other sports
- 6 – 12 swim-specific, including land work\(^a\)
- 8 – 12 swim-specific, including land work\(^a\)
- 10 – 15 swim-specific, including land work\(^a\)

Recommended number of hours per week
- 2.5 – 4.5 hours general sports
- 4 – 7 hours swimming, plus 1 – 2 hours land work\(^a\)
- 12 – 24 hours swimming, plus 2 – 3 hours land work\(^a\)
- 16 – 24 hours swimming, plus 3 – 4 hours land work\(^a\)
- 20 – 24 hours swimming, 3 – 6 hours land work\(^a\)

Recommended training volume per week
- None stated
- 8,000 – 16,000 m
- 24,000 – 32,000 m
- 24,000 – 52,000+ m
- > 44,000 m, depending on specialism\(^b\) (s)

\(^a\)Land work, strength and conditioning training; \(^b\)Specialism, specialist swimming stroke (s).

The overemphasis on training volume, particularly during the Training to Train stage (12 – 24 hours of swimming per week), is in line with the recommendations of Balyi and Hamilton (2004) who suggest a “window of opportunity” exists for aerobic development during the onset of maturation (males 12 – 15 years and females 11 – 14 years) and therefore the aim should be to “build the engine” using HVT. An expert commentary article by Greyson et al. (2010) on the Lang and Light (2010) study
suggests that HVT is vital during the Training to Train stage in order to optimise training adaptations during the “window of opportunity” for aerobic development. Greyson et al. (2010) suggests that optimising the development of the aerobic energy system during maturation is crucial in later years to all who swim competitively as the aerobic system is linked to the effective recovery of the swimmer during HIT and competition, which often involves heats, semi-finals and finals at senior level. In addition, Greyson et al. (2010) suggests that HVT during the Training to Train stage will maximise the development of the diaphragm and thorax which are at their peak growth rate during this stage. The authors conclude that too much anaerobic training during the Training to Train stage will result in a reduction in a swimmer’s potential to be a successful senior swimmer.

A review article by Ford et al. (2011) examined the literature in order to evaluate any potential evidence for the “windows of opportunity” as proposed in the LTAD model. Ford et al. (2011) concluded that the evidence in support of the “windows of opportunity” is largely anecdotal and the concept lacks empirical evidence, therefore adapting training prescriptions based on these “windows” should be considered with caution. In particular, there are risks associated with early specialization and intensive training if the “windows of opportunity” are taken too literally, as appears to have happened with the adapted LTAD model for swimming in the Lang and Light (2010) study. Despite this, the LTAD model has advanced coaches and practitioners understanding of the importance of physiological principles and biological maturation during the training of youths (Ford et al. 2011). In recent years, the Youth Physical Development (YPD) model has become increasingly popular and is suggested to provide a more evidence based approach to youth development (Lloyd and Oliver 2012). The YPD model provides an overview of athletic development from early childhood (2 years of age) to adulthood (21+ years of age) while identifying when and why the training of each athletic component (i.e. strength, power, speed, mobility, agility, endurance, etc.) should be emphasised (Lloyd and Oliver 2012). The philosophy of the YPD model permits individualisation, is athlete centred and promotes the development of the child over performance outcomes (Lloyd and Oliver 2012). However, the LTAD model is still widely utilised in Ireland and therefore the training recommendations of each developmental stage for Irish swimmers would be of interest for the purpose of this thesis.
2.5 Introduction to Training Theory

In order to understand the training practices within any sport, a clear understanding of basic training theory must first be evident. Training is an organised process whereby the athlete is exposed to stressors of varied volume, intensity and frequency interspersed with periods of rest and recovery. The objective of training is to improve performance by progressively and systematically increasing the training stressors (i.e. volume, intensity and frequency of training) in order to induce a training adaptation (Stone et al. 2007). A widely recognised theory of training adaptation is the general adaptation syndrome (GAS) which was first proposed by Hans Selye (Selye 1950) and is summarised in Figure 2.2. The GAS theory suggests that a training stressor results in an initial alarm phase which leads to a decrease in performance (P) due to soreness, stiffness and fatigue (Stone et al. 2007). Over time (T), the alarm phase sets in motion adaptive mechanisms which lead to the resistance phase. During the resistance phase, positive adaptations can occur which either return the body to baseline homeostasis or return it to a new and adapted higher state (i.e. supercompensation) (Stone et al. 2007). However if the accumulation of training stressors is too great (e.g. the prescribed training volume or intensity is too high to recover from), then the exhaustion stage can occur which leads to overtraining (Stone et al. 2007).

Figure 2.2 – Hans Selye’s general adaptation syndrome (GAS), adapted by Turner (2011). Abbreviations: P, performance; T, time.

Other similar theories of training adaptation have been suggested in the literature such as Yakovlev’s stimulus-fatigue-recovery-adaptation model (Yakovlev 1967) and Bannister’s fitness-fatigue model (Bannister 1991). However, the degree of training
adaptation is highly specific to the type of training undertaken, therefore training programmes must be based on the dominant energy systems of the sport, the skills of the sport and the motor abilities required by the sport (Bompa and Haff 2009). The principle of training specificity suggests that training adaptations only occur in the muscle fibres that have been recruited during the training programme and therefore the closer the training programme is to the requirements of the desired outcome (e.e. improving 50 m breaststroke performance, 200 m freestyle performance, etc.), the better the outcome (Hawley 2008).

The traditional HVT practices of competitive swimmers have been suggested to violate the principle of training specificity (Costill et al. 1991), particularly for sprint to middle distance events (i.e. 50, 100 and 200 m events) which typically take less than 2 minutes 20 seconds at the elite level. David Costill was one of the earliest researchers to investigate this topic and he summarises it by stating “it is difficult to understand how swimming at speeds that are markedly slower than competitive pace for 3 to 4 hours per day will prepare the swimmer for the supramaximal efforts of competition”(Costill et al. 1991). Similar criticisms of HVT have been made by prominent swimming coaches and researchers (Salo and Riewald 2008a, Treffene 2010).

In recent years, there has been an evident shift towards swimming training programmes that aim to adhere to the principle of specificity such as HIT or Ultra-Short Race-Pace Training (USRPT) programmes (Faude et al. 2008, Sperlich et al. 2010, Kilen et al. 2014, Rushall 2015, Salo 2015). Ultra-Short Race-Pace Training is defined as high intensity swimming in sets that match the best achieved velocities of individuals’ races and consists of a high number of repetitions over short distances with brief rests, generally no longer than 20 seconds (Rushall 2011). A USRPT programme has been suggested to be more specific to the physiological, biomechanical and psychological demands of competitive swimming (Rushall 2011).

2.6 Establishing Training Zones

In the sport of swimming, one of the most important training stressors is the overall training volume within a programme which can be subdivided into different training intensities or zones. Establishing training zones helps coaches to successfully plan a training programme through ensuring regular exposure to a variety of training stressors
while controlling for negative effects such as overtraining. Most national and international governing bodies employ some form of training zone model for coaches based on recommended heart rate ranges relative to maximum and associated range of typical blood lactate concentrations. An example of a five-zone model that is widely utilised in an Irish swimming context is detailed below in Table 2.3.

Table 2.3 A five-zone training model commonly utilised in Irish swimming (Sweetenham and Atkinson 2003)

<table>
<thead>
<tr>
<th>Training Zone</th>
<th>Description</th>
<th>HR (bbm)</th>
<th>BLa (mM)</th>
<th>RPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 1</td>
<td>Aerobic Low Intensity (i.e. Base conditioning and technical training)</td>
<td>&gt;50</td>
<td>&lt; 2</td>
<td>&lt; 9</td>
</tr>
<tr>
<td></td>
<td>Aerobic Maintenance/Development (i.e. Base aerobic training)</td>
<td>40 – 50</td>
<td>2 – 4</td>
<td>10 – 12</td>
</tr>
<tr>
<td>Zone 2</td>
<td>Anaerobic Threshold (i.e. Training at maximal lactate steady state)</td>
<td>20 – 30</td>
<td>3 – 6</td>
<td>14 – 15</td>
</tr>
<tr>
<td>Zone 3</td>
<td>Aerobic Overload (i.e. High-intensity training at $V_{O2}^{max}$. Includes heart rate and critical velocity training)</td>
<td>5 – 20</td>
<td>6 – 12</td>
<td>17 – 19</td>
</tr>
<tr>
<td>Zone 4</td>
<td>Lactate Production (i.e. Race pace training)</td>
<td>5 – 15</td>
<td>8 – 15</td>
<td>17 – 19</td>
</tr>
<tr>
<td></td>
<td>Lactate Production/Tolerance (i.e. High-intensity training with medium rest)</td>
<td>0 – 10</td>
<td>12 – 20</td>
<td>19 – 20</td>
</tr>
<tr>
<td>Zone 5</td>
<td>Sprinting – ATP-PC (i.e. High intensity training of short duration with long rest intervals)</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

Abbreviations: HR (bbm), heart rate measured in beats below maximal; BLa, blood lactate concentration; RPE, rating of perceived exertion (6 – 20 scale)

However, generic training zone guidelines such as Table 2.3 fail to account for individual variation in the relationship between heart rate and blood lactate responses or activity specific variation in response to exercise (Seiler 2010). In addition, many of the boundaries between each training zone are not clearly anchored in underlying physiological events (Seiler and Kjerland 2006). For example, the difference between zone 3 and zone 4 in Table 2.3 is entirely dependent on heart rate and blood lactate values. A number of recent studies have used the first and second ventilatory turn points to distinguish a three-zone model (see Figure 2.3) (Esteve-Lanao et al. 2005, Seiler and Kjerland 2006, Zapico et al. 2007, Seiler 2010). The first (VT$_1$) and second ventilatory turn points (VT$_2$) were previously identified in studies using breath-by-breath gas
exchange measurements and represent ventilatory changes that have been found to correspond to the aerobic (LT₁) and anaerobic (LT₂) thresholds (Seiler 2010). The advantage of a three-zone model, as seen in Figure 2.3, over a five-zone model is that the ventilatory measurements provide two clearly defined physiological events that are practical to identify in a laboratory setting (Seiler and Tønnessen 2009). The three-zone model can be divided into low-intensity training (Zone 1), moderate-intensity training (Zone 2) and high-intensity training (Zone 3) (Seiler and Kjerland 2006).

Figure 2.3 – A three-zone training model proposed by Seiler and Kjerland (2006). Abbreviations: La’, blood lactate concentration; VO₂max, maximal oxygen uptake; VT, ventilatory threshold; LT, lactate threshold; MLSS, maximal lactate steady state.

2.7 Quantifying and Prescribing Training Zones
Accurately quantifying and prescribing each training zone requires a combination of methods such as velocity at lactate or ventilatory thresholds, percentage of maximal heart rate or VO₂max, blood lactate concentration and rating of perceived exertion (RPE) (Hydren and Cohen 2015). This is due to the limitations associated with depending on one method alone (e.g. individual variations in heart rate or blood lactate concentration). Low-intensity training (LIT) or “zone 1” training is defined as continuous training performed below VT₁ and LT₁, or at stable blood lactate concentrations of < 2 mM (Seiler 2010). Typical heart rate values for LIT are < 80% of maximal heart rate (HRmax) (Seiler 2010). Rating of perceived exertion values for LIT sessions have been
suggested to be ≤ 4 for the Borg 1 – 10 scale and ≤ 13 for the Borg 6 – 20 scale (Hydren and Cohen 2015). Low-intensity training is often performed in high-volumes, which is commonly referred to as a low-intensity, high-volume (HVT) training programme (Stoggl and Sperlich 2015).

Moderate-intensity training (MIT) or “zone 2” training is defined as training performed between VT₁ or LT₁ and VT₂ or LT₂, or at blood lactate concentrations of 2 to 4 mM (Seiler 2010). Typical heart rate values for MIT range from 80 – 87% of HRmax (Seiler 2010) while RPE values of 5 – 6 for the Borg 1 – 10 scale and 14 – 16 for the Borg 6 – 20 scale have been suggested (Hydren and Cohen 2015). Moderate-intensity training is often performed in a continuous or interval training format and is commonly referred to as a threshold training programme (Stoggl and Sperlich 2015).

High-intensity training (HIT) or “zone 3” training is defined as training performed above VT₂ and LT₂, or at blood lactate concentrations of > 4 mM. This is usually performed in an interval training format as repeated short (< 45 seconds) to long (2 – 4 minutes) bouts of exercise interspersed with active or passive recovery periods (Buchheit and Laursen 2013b). The recovery periods are generally fixed work-recovery ratios (e.g. 1:1, 1:2 or 2:1) or based on heart rate returning to a fixed percentage of its maximum (Laursen and Jenkins 2002). Typical heart rate values for prescribing HIT range are > 87% of HRmax (Seiler 2010) while RPE values of ≥ 7 for the Borg 1 – 10 scale and ≥ 17 for the Borg 9 – 20 scale have been suggested (Hydren and Cohen 2015). High-intensity training is often performed in lower volumes than other training zones due to the associated physiological demand and is commonly referred to as a low-volume, high-intensity training programme (Gibala et al. 2012).

2.8 Applications and Adaptations of each Training Zone

2.8.1 Low-Intensity Training

Elite and well-trained athletes are widely known for completing large amounts of LIT during both preparation and competition phases of the training season (Seiler and Kjerland 2006, Seiler 2010, Stoggl and Sperlich 2015). Cyclical sports such as rowing (Plews et al. 2014), cycling (Zapico et al. 2007), cross country skiing (Seiler and Kjerland 2006) and running (Esteve-Lanao et al. 2005) have been found to complete 70 – 94% of their training as LIT. Elite senior swimmers have been found to complete 80%
of their training as LIT (Mujika et al. 1995) which is similar to the recommendations of swim coaches for both youth and elite swimmers across all events (Maglischo 2003a, Sweetenham and Atkinson 2003). In fact, Alexander Popov, the double Olympic champion in the 50 and 100 m freestyle, was reported to perform at least 1 hour of LIT per day throughout the entire season despite competing in sprint events of < 50 seconds duration (Maglischo 2003e).

The training adaptations that occur due to LIT are multifactorial in nature and result in profound changes to physiological and neuromuscular systems within the body (Laursen 2010). Physiological adaptations that occur due to LIT include increased blood and plasma volume, increased cardiac output, increased muscle and cutaneous blood flow, changes in muscle capillary density and mitochondrial volume (Laursen and Jenkins 2002). These physiological adaptations result in the increased delivery of oxygen to the muscle during exercise in combination with an increased utilisation of oxygen by the muscle. However many of these adaptations have only been found in recreationally active and untrained individuals, therefore these physiological adaptations may not occur to the same extent in well-trained athletes (Laursen and Jenkins 2002). Despite this, numerous performance adaptations due to LIT are commonly seen in well-trained athletes such as increased $\dot{V}O_{2max}$ (Hickson et al. 1981, Carte et al. 1999, Pugliese et al. 2015), improved exercise economy (Jones 1998, Billat et al. 1999, Jones and Carter 2000, Enoksen et al. 2011), increased velocity at $\dot{V}O_{2max}$ (Jones 1998, Billat et al. 1999, Jones and Carter 2000), and increased velocity at LT₁ and LT₂ (Jones and Carter 2000, Pugliese et al. 2015, Ni Cheilleachair et al. 2017). These performance adaptations are the result of increased oxygen delivery and extraction in working muscles, thus efficiency improves and consequently physical work capacity increases which should have a direct impact on performance (Laursen and Jenkins 2002).

In addition to the physiological and performance adaptations to LIT, there are also numerous practical applications of incorporating LIT into the training programmes of cyclical sports such as swimming. A review article by Elliott et al. (2007) suggests LIT helps to improve recovery from HIT, increases glucose uptake, improves body composition and helps to prepare musculoskeletal structures for more intense training. The proposed mechanisms behind LIT improving recovery are that the increases to muscle capillarization provided by LIT may help to improve the delivery of oxygen to working muscles and thus increase the removal of metabolic by-products (Elliott et al.
2007). This is an important factor to consider if recovery during and after HIT sessions or competitions is to be optimised (Laursen 2010), particularly in a sport like swimming where athletes typically compete in numerous events across multi-day competitions. In support of this, swimming coaches have previously highlighted that LIT is important in the recovery process (Greyson et al. 2010). Improving body composition is also another important factor that has been previously mentioned (Greyson et al. 2010, Laursen 2010) and may be crucial for swimmers who must maintain a lean body profile in order to decrease form drag through the water, particularly in female swimmers (see 2.3 The biomechanical demands of swimming).

Another potential application of LIT is engraining and optimising the neuromuscular pattern of the sport (Ingham et al. 2008, Greyson et al. 2010, Laursen 2010). Swimming is a cyclical movement meaning that the muscle action is repetitive in nature and therefore technical ability is developed through repetition of the movement pattern (Bompa and Haff 2009). This could be of vital importance in swimming due to the complex interplay between physiology and biomechanics which suggests that the technical ability of a swimmer in decreasing resistance or drag and increasing propulsion is directly linked to the physiological requirements (Pyne and Sharp 2014). Developing efficient swimming technique may also require a much larger amount of iterative repetition than innate actions like running (Ingham et al. 2008). In addition, swimming is a non-weight bearing sport similar to rowing and cycling, therefore the eccentric demands on the musculoskeletal system are minimal. Consequently, swimmers can train longer without experiencing the same degree of eccentric muscle damage as weight-bearing sports.

2.8.2 Moderate-Intensity Training
Elite senior swimmers have been shown to complete around 10% of their training as MIT (Mujika et al. 1995), however this percentage distribution of MIT may vary depending on the swimmers age cohort or competitive event (Maglischo 2003e, Sweetenham and Atkinson 2003). The popularity of LIT in swimming programmes means that some MIT is often performed by mistake, particularly at youth level, as the physiological demands of each swimming stroke may vary depending on the swimmer’s biomechanical or technical efficiency (Barbosa et al. 2006, Barbosa et al. 2010a). Moderate-intensity training has previously been suggested as the optimum training intensity or zone to elicit physiological and performance adaptations in endurance
events (Kindermann et al. 1979). However, the popularity of MIT for swimmers may be decreasing due to the increasing popularity of LIT and HIT among the academic and coaching community (Laursen 2010, Seiler 2010, Stott 2014, Goldsmith 2016). While MIT is not a primary focus of this thesis, the physiological and performance adaptations appear to be similar to LIT (Keith et al. 1992). However MIT is performed at higher intensities (2 – 4 mM blood lactate) than LIT (< 2 mM blood lactate) which may therefore result in greater physiological stress levels (Seiler et al. 2007).

Inducing greater physiological stress levels on the athlete is an important consideration when using MIT within training programmes. A study by Seiler et al. (2007) investigated the effects of LIT and MIT sessions on the acute recovery of the autonomic nervous system (ANS) in well-trained runners. The LIT sessions involved either 1 or 2 hours of LIT performed below VT1 and the MIT session involved a 1 hour session with 30 minutes of MIT performed between VT1 and VT2. Recovery of the ANS was assessed using heart rate variability and both LIT sessions were found to cause less autonomic stress than the MIT session. This may be a contributory factor as to why elite and well-trained athletes complete a large percentage of their training as LIT.

2.8.3 High-Intensity Training

Coaches have long used HIT in various formats to improve athletic performance (Hawley et al. 1997). Although the specific origins of the term can be debated, many suggest that the original term of “interval training” can be credited to the German athletics coach Waldemer Gershler in the 1930’s (Billat 2001, Seiler and Tønnessen 2009). Gershler, who was said to have been heavily influenced by the physiologist Dr. Hans Reindell, believed that alternating periods of hard exercise and recovery was an effective stimulus for developing the heart. In the late 1940s and throughout the 1950s, numerous highly successful runners were reported to be using interval training (Billat 2001). During this period, the most famous runner to have had success with interval training was Emil Zatopek who won the gold medal in the 5,000 m, 10,000 m and marathon events in the 1952 Olympics. The earliest published work on interval training was by a group of Swedish physiologists, led by Per-Olof Åstrand, who demonstrated how the manipulation of exercise duration and rest duration could dramatically impact the physiological responses to intermittent exercise (Åstrand et al. 1960, Christensen et al. 1960). This pioneering work laid the foundation for all interval training and thus HIT research to follow (Billat 2001).
The specific amounts of HIT performed by well-trained athletes in cyclical sports has been shown to vary widely from 1 to 57%, depending on the training model utilised (Stoggl and Sperlich 2014). The amount of HIT prescribed by swimming coaches may depend on the stage of the season, the event specific or individual needs of the swimmer(s) and the coaches’ preferred training model (Maglischo 2003e). Sweetenham and Atkinson (2003) suggests 5 – 30% of training should be race pace/HIT. However, there are examples of highly successful international swimmers using almost exclusively HIT. Michael Andrews, the 2016 World Champion in the 100 m medley event, has been reported to have a training volume of 9 – 11 km per week using a USRPT programme (Stott 2014) which is similar to HIT. This is in stark contrast to the training records of other sprint swimmers such as Alexander Popov, the double Olympic champion in the 50 and 100 m freestyle, who was reported to have a training volume of 40 – 100 km per week depending on the stage of the season and was comprised primarily of LIT (Maglischo 2003e).

In the past two decades, a number of reviews investigating HIT have been conducted (Laursen and Jenkins 2002, Laursen 2010, Gibala et al. 2012, Buchheit and Laursen 2013a, Buchheit and Laursen 2013b, Bangsbo 2015). The physiological and performance adaptations that occur due to HIT are similar in nature to both LIT and MIT but often occur more rapidly and to a greater degree, particularly for athletes who have not previously performed HIT (Seiler 2010). A review by Gibala et al. (2012) suggests that the physiological adaptations that occur due to HIT include increased skeletal muscle oxidative capacity, increased resting glycogen content, reduced rate of glycogen utilization and lactate production during matched-work exercise, increased capacity for whole-body and skeletal muscle lipid oxidation and enhanced peripheral vascular structure and function. However, the majority of these physiological adaptations to HIT were found in studies on recreationally active or sedentary individuals which is a limitation of the current literature in this area.

A large number of HIT studies have been conducted on well-trained youth and senior level athletes in cyclical sports such as cycling (Weston et al. 1996, Westgarth-Taylor et al. 1997, Laursen et al. 2002, Creer et al. 2004), rowing (Driller et al. 2009, Akca and Aras 2015, Ni Cheilleachair et al. 2017), swimming (Faude et al. 2008, Kilen et al. 2014), running (Iaia et al. 2008, Enoksen et al. 2011, Kohn et al. 2011) and cross
country skiing (Sandbakk et al. 2013, Stoggl and Sperlich 2014). Physiological adaptations that have been found to occur due to HIT interventions in well-trained athletes include increased skeletal muscle lipid oxidation (Westgarth-Taylor et al. 1997), increased skeletal muscle buffering capacity (Weston et al. 1996), increased ability to engage a greater volume of muscle mass (i.e. recruitment of fast twitch motor units) (Creer et al. 2004, Enoka and Duchateau 2008), but no adaptations to skeletal muscle oxidative capacity have been found to occur (Iaia et al. 2008, Kohn et al. 2011) which is in contrast to previous findings (Laursen and Jenkins 2002). However, inconsistencies in the physiological adaptations to HIT may be due to the short 4 week duration of many of the HIT studies and the well-trained status of the participants (Weston et al. 1996, Laursen et al. 2002, Creer et al. 2004, Faude et al. 2008, Driller et al. 2009), which could potentially limit short term physiological adaptations.

Despite this, numerous performance adaptations to HIT have been consistently found to occur such as increased \( \dot{V}O_2\text{max} \) (Laursen et al. 2002, Creer et al. 2004, Driller et al. 2009, Sandbakk et al. 2013, Akca and Aras 2015, Ni Cheilleachair et al. 2017), velocity at \( \dot{V}O_2\text{max} \) (Weston et al. 1996, Westgarth-Taylor et al. 1997, Laursen et al. 2002, Creer et al. 2004, Sandbakk et al. 2013, Akca and Aras 2015) and velocity at LT1 or LT2 (Driller et al. 2009, Akca and Aras 2015, Ni Cheilleachair et al. 2017). Consequently, HIT interventions have been consistently found to increase performance in events from 30 seconds to 40 minutes duration (Weston et al. 1996, Westgarth-Taylor et al. 1997, Laursen et al. 2002, Driller et al. 2009, Sandbakk et al. 2013, Akca and Aras 2015, Ni Cheilleachair et al. 2017). The numerous physiological and performance adaptations of HIT could potentially have even greater applications in a non-weight bearing sport such as swimming. Due to its non-weight bearing nature, the eccentric demands on the musculoskeletal system in swimming are minimal, in comparison to a weight-bearing sport like running, which means that swimmers can potentially perform greater volumes of HIT and thus promote greater physiological and performance adaptations.

Another potential application of HIT is optimising swimming biomechanics at competitive race pace intensities (De Jesus et al. 2016). Studies involving two and three-dimensional kinematic analysis have found that as swimming intensity increases – SR increases (Fernandes et al. 2011, Figueiredo et al. 2013, Barbosa et al. 2015, De Jesus et al. 2016) and SL decreases (Fernandes et al. 2011, Figueiredo et al. 2013, Barbosa et al. 2015, De Jesus et al. 2016), while SI remains stable (Oliveira et al. 2012,
Barbosa et al. 2015). The most prominent biomechanical modifications to swimming technique occurred at swimming intensities above the LT2 (i.e. zone 3 or HIT) (De Jesus et al. 2016) therefore HIT may be a valuable tool to optimise swimming biomechanics.

2.9 Molecular Pathways of HIT and HVT

The molecular events that lead to the adaptation of skeletal muscle to different training intensities are still not fully understood, however a number of recent reviews provide some insight and understanding of this complex topic (Coffey and Hawley 2007, Laursen 2010, Gibala et al. 2012). Periods of HIT, which typically involve high energy contractions, are suggested to lead to reductions in intramuscular ATP (adenosine triphosphate) concentrations which elicit a concomitant rise in adenosine monophosphate (AMP) (see Figure 2.4) (Laursen 2010, Gibala et al. 2012). This leads to activation of AMP-activated protein kinase (AMPK) which results in an increase in peroxisome proliferator-activated receptor-y coactivator-1α (PGC-1α), which has been described by some as the master switch of mitochondrial biogenesis in muscle (Laursen 2010, Gibala et al. 2012).

Prolonged periods of high-volume training at low intensities (HVT), which involve long durations of repeated muscular contractions, are suggested to lead to a rise in intramuscular calcium concentration (Ca^{2+}) which in turn activates a mitochondrial biogenesis messenger called the calcium-calmodulin kinases (CaMK) (Laursen 2010). Similarly, the increases in CaMK lead to an increase in PGC-1 α. Therefore, both HIT and HVT appear to have different signalling mechanisms but similar downstream targets as seen in Figure 2.4. Consequently, Laursen (2010) suggests that the high mitochondrial oxidative capacity, improved fat oxidative potential and increased glucose transport capacity in the skeletal muscle of endurance athletes may be achieved through either HIT, HVT or a combination of both.
2.10 Summary

Competitive swimming is a complex and demanding sport. High training volumes of around 16 hours per week are common for youth swimmers. However, there are numerous risks associated with high training volumes such as early specialisation, overuse injury and overtraining syndrome. Youth development models such as the YPD suggest a more holistic approach should be taken to develop youth athletes which involves building strength, developing movement skill competency, fostering creativity and increasing enjoyment through games and free play. Logistically it is difficult to see how these opportunities, as suggested by the YPD amongst others, can be created when HVT is the dominant training practice of competitive youth swimmers.

Coaches from a variety of endurance sports have long used HIT in various formats to improve athletic performance. A number of recent reviews have concluded that HIT interventions can improve physiological and performance parameters in cyclical sports such as rowing, cycling, running, kayaking and cross-country skiing. However, research
on competitive swimmers is limited and warrants further investigation. The advantage of a HIT programme is the lower training volume due to the increased physiological demand from working at a higher intensity. This could potentially be advantageous for coaches and sport scientists who are working with youth swimmers that may have limited training time due to school timetables, participation in multiple sports or the commonly restricted training hours for competitive swimming clubs in public facilities. In addition, there are examples of highly successful international swimmers using almost exclusively HIT which has increased debate among the swimming community and academics. Clearly, further research on the effect and efficacy of HIT versus HVT in competitive youth swimmers is required.
Chapter 3: Study 1 – Effects of Low-Volume, High-Intensity Training on Performance in Competitive Swimmers: A Systematic Review

3.1 Abstract

Purpose: The aim of this systematic review was to examine the extent and quality of the current research literature in order to determine the effects of low-volume, high-intensity training (HIT) on physiological performance and swimming performance in competitive swimmers. Methods: The methodology followed the PRISMA-P protocol. A search of relevant databases and conference proceedings was performed until December 2015. The inclusion criteria was: a) competitive swimmers, b) ≥ 4 weeks HIT intervention, c) comparison group had to involve a higher training volume, d) outcome measures of physiological and swimming performance, e) all experimental study designs. Quality assessment was performed using the Quality Index Checklist. Results: Of the 538 studies retrieved, seven studies met the inclusion criteria. Six out of the 7 studies found that a HIT intervention resulted in significant improvements in physiological performance. Four of the 7 studies found that HIT resulted in significant improvements in swimming performance, whilst none of the 7 studies resulted in a reduction in physiological or swimming performance. Conclusion: Despite the positive findings of this review, the short study duration is a limitation of a number of the studies. The current evidence on the effects of HIT on performance is promising however it is difficult to draw accurate conclusions until further research has been conducted.
3.2 Introduction

In recent years, HIT has become a training methodology that is receiving an increasing amount of investigation as it may allow for a reduction in the overall training volume, through an increase in training intensity (Laursen and Jenkins 2002). This training methodology may potentially be more specific to the physiological and biomechanical demands of the majority of swimming events as 76% of Olympic level events are competed over 200 m or less, for a typical duration of less than 2 minutes 20 seconds.

Interventions involving HIT training have been performed in a large variety of sporting events such as rowing (Ingham et al. 2008, Driller et al. 2009, Akca and Aras 2015), middle to long distance running (Iaia et al. 2008, Enoksen et al. 2011, Ferley et al. 2014), cycling (Creer et al. 2004, Laursen et al. 2005, Swart et al. 2009, Rønnestad et al. 2014), tennis (Fernandez-Fernandez et al. 2012) and soccer (Dupont et al. 2004, Sperlich et al. 2011, Faude et al. 2013, Slettaløkken and Rønnestad 2014). Sports that are characterised by performing HVT such as cycling, long distance running, rowing and swimming have been found to benefit from HIT interventions (Laursen 2010).

A reduction in training volume through implementing a HIT intervention could potentially have many beneficial effects on the overall health and longevity of competitive swimmers. An excessive focus on HVT has been linked to an increased risk of shoulder injury (Sein et al. 2010, Madsen et al. 2011) and overtraining syndrome (Hooper et al. 1993, Raglin et al. 2000) in competitive swimmers. In addition, high volumes of training from a young age have been suggested to increase the risk of early specialisation (Moesch et al. 2011, Jayanthi et al. 2013, Myer et al. 2015a, Myer et al. 2015b), therefore training methods that may allow for a reduction in training volume are of interest.

A sound scientific evidence base for the adoption of this traditional HVT approach to competitive swimmers remains equivocal. Previous systematic reviews have investigated swimming energetics in elite swimmers (Aspenes and Karlsen 2012, Costa et al. 2012, Costa et al. 2015) however a detailed review of the current research involving HIT interventions in competitive swimmers is lacking. The purpose of this systematic review was to examine the extent and quality of the current research literature in order to determine the effects of HIT on physiological performance and swimming performance in competitive swimmers.
3.3 Methods

The methodology outlined in the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA-P) document was used in this systematic review (Shamseer et al. 2015). In accordance with the guidelines outlined in the PRISMA-P document, the systematic review was registered with the International Prospective Register of Systematic Reviews (PROSPERO) on 18th December 2015 and was last updated on the 2nd March 2016 (registration number CRD42015030049). The structure of this systematic review involved the following five stages.

Stage 1. A comprehensive search of the MEDLINE, SPORTDiscus, ScienceDirect and PubMed databases was conducted on the 16th December 2015. The Faculty of Education and Health Sciences librarian at the University of Limerick assisted in the development of the specific search strategy. The following search strategy was used: swim* AND (Comp* OR youth OR young OR elite OR national OR regional OR international OR master) AND (intensity OR high intensity training OR reduc* volume OR low volume) NOT (rat OR mouse OR mice OR fish). The search was limited to the English language, human subjects and studies published after 1970. In addition to database searching, manual searches were performed among the references from the Biomechanics and Medicine in Swimming Conference (volume 1, 1970 to volume 12, 2014) and the Journal of Swimming Research. Prominent authors in the subject area were also contacted in order to locate any additional relevant studies and manual searches were performed among the reference lists of the identified studies.

Stage 2. Studies were eligible if they met the inclusion criteria outlined in Table 3.1. Competitive swimmers were defined as male or females, ≥ 10 year’s old, training ≥ 3 days per week for ≥ 3 years and competing at a minimum of regional level. The outcome measures of physiological performance included peak or maximal rate of oxygen consumption (\(\dot{V}O_{\text{peak}}\) or \(\dot{V}O_{\text{max}}\)), sub-maximal lactate indices (\(BLa_{\text{submax}}\) – velocity at blood lactate concentrations of 2 and 4 mM) and peak lactate indices (\(BLa_{\text{peak}}\) – peak rate of blood lactate accumulation post exercise). The outcome measure of swimming performance was defined as a maximal time trial (TTP) or competitive performance (CP) over any distance. The lead author (FJN) performed a detailed investigation during the planning stage of the review to ensure that the selected outcomes were relevant.
Stage 3. The first stage of screening the studies was conducted by two reviewers (FJN and EB) who independently screened the literature titles and abstracts before comparing results. The second stage involved the independent reviewers (FJN and EB) retrieving and screening full text studies, the results were then compared to determine inclusion in the systematic review. Once a final decision had been reached through consensus, the selected studies were included for further analysis in the systematic review. The PRISMA flow chart of the study selection process is summarised in Figure 3.1.

Table 3.1 Inclusion criteria

- Competitive swimmers.
- Intervention consisted of HIT for ≥ 4 weeks.
- Comparison group had to involve a higher training volume (distance or duration) per session.
- Outcome measures of physiological performance and swimming performance.
- All experimental study designs

Stage 4. Quality assessment of the seven studies that met the inclusion criteria was performed using the Quality Index checklist (QI) proposed by Downs and Black (1998). The QI has been shown to be a valid and reliable tool for assessing the methodological quality of both randomised controlled trials and non-randomised controlled studies (Downs and Black 1998). The QI consists of 27 items that are divided into five subscales: reporting (10 items), external validity (3 items), internal validity – bias (7 items), internal validity – confounding (6 items) and power (1 item). The QI has a maximum score of 32 points with each item scoring 0 or 1, except for a 2 point score for describing the distribution of principle confounders, and a 5 point score for a sufficient power calculation. Two independent reviewers (FJN and EB) evaluated each of the seven studies using the QI. Consensus was achieved on scores given to the seven studies. A third reviewer was not needed to resolve differences in scores and the Kappa value for all seven studies was 1.0 (perfect agreement).

Stage 5. The seven selected studies were not suitable for quantitative synthesis (meta-analysis) due to a lack of homogeneity in terms of study design and data analysis. As a result, a qualitative synthesis was used to summarise and explain the characteristics and findings of the included studies (see Table 3.3 and 3.4). The format used for the qualitative synthesis included information about the study citation, description of participants (demographics, competitive level, training history), description of
intervention (duration, intervention, comparison group), performance outcome measures and results. Two independent reviewers (FJN and EB) manually extracted the article data using tables created on Microsoft Excel™ and results were compared. Authors of included articles were contacted in the absence of the required information.

**Figure 3.1 – PRISMA flow chart**
3.4 Results

The QI was selected due to the absence of a validated quality assessment tool for assessing the methodological quality of sports performance studies. The QI score of the seven studies had a mean of 16.1 points (range: 7 to 22) out of a maximum of 32 possible points (Table 3.2). Across the seven studies, the strengths were reporting and internal validity – bias. The weaknesses were external validity, internal validity – confounding and power. None of the studies provided a power calculation therefore the power item received 0 out of 5 in all studies.

Seven studies investigated the effects of a HIT intervention on physiological performance and swimming performance in youth swimmers (Faude et al. 2008, Sperlich et al. 2010), elite swimmers (Kilen et al. 2014), university swimmers (Houston et al. 1981, Kame et al. 1990, Termin and Pendergast 2000) and master swimmers (Pugliese et al. 2015). Six out of the 7 studies found that a HIT intervention resulted in significant improvements to physiological performance, both aerobic (Houston et al. 1981, Kame et al. 1990, Termin and Pendergast 2000, Faude et al. 2008, Sperlich et al. 2010, Pugliese et al. 2015) and anaerobic (Termin and Pendergast 2000, Sperlich et al. 2010) (Tables 3.3 and 3.4). Four of the 7 studies found that HIT resulted in significant improvements to swimming performance, both time trial performance (TTP) and competitive performance (CP) in events from 50 to 2,000 m (Kame et al. 1990, Termin and Pendergast 2000, Sperlich et al. 2010, Pugliese et al. 2015). None of the seven studies resulted in a reduction in physiological or swimming performance following a HIT intervention.
Table 3.2 Quality index checklist

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<td>Authors</td>
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<tr>
<td>Sperlich et al.</td>
<td>26</td>
<td>13 M/13 F</td>
<td>10.5 ± 1.4</td>
<td>Regional to national youth level</td>
<td>Training ≥ 4 days per week and competing for ≥ 3 years in 50 – 100 m events.</td>
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<td>(2010)</td>
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</table>
| Faude et al. (2008)| 10 | 6 M/4 F   | 16.6 ± 1.4      | Regional to national youth level | Training on average 20 hours per week and competing in 100 – 400 m events.  
Nine out of ten swimmers were ranked in the top 10 or better in the national age group rankings. |
<p>| Kilen et al. (2014)| 41 | 30 M/11 F | 20.0 ± 2.7      | Elite senior level | Training ≥ 5 years for 8 – 16 hours per week with an average weekly training volume of 20,000 – 60,000 m and competing in 50 – 200 m events. Two swimmers specialized in 400 m and 800 m events. |
| Kame et al. (1990) | 17 | 17 M/0 F  | 19.1 ± 0.2      | Competitive university level | Division 2 swimmers. Previous season’s training consisted of 2 sessions per day covering a total distance of 10,000 – 12,000 yards |
| Ternin and Pendergast (2000) | 22 | 22 M/0 F  | 19.0 ± 0.2      | Competitive university level | Division 1 swimmers. Pre-college training volume of 60,000 – 80,000 yards per week. 100 yard freestyle PB times of 48.66 ± 0.7 s and 200 yard freestyle PB times of 1:50.17 ± 2.72 s. |
| Houston et al.     | 10 | 7 M/3 F   | 19.8 ± 0.4      | Competitive university level | Training 9.4 ± 3.7 years. Only 4 swimmers had trained in the 4 months prior to the study. |
| (1981)             |    |           |                 |                   |                                                                                  |
| Pugliese et al.    | 10 | 10 M/0 F  | 32.3 ± 5.1      | Elite masters level | Training 11 ± 4 years on average 3 km per day, 3 times per week and competing in 50 – 400 m events. Competed at World Masters Championships. |
| (2015)             |    |           |                 |                   |                                                                                  |</p>
<table>
<thead>
<tr>
<th>Authors, year</th>
<th>Duration (weeks)</th>
<th>Study design</th>
<th>Intervention group</th>
<th>Control/comparison group</th>
<th>Physiological performance outcome measure(s)</th>
<th>Swimming performance outcome measure(s)</th>
<th>Results</th>
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<tr>
<td>Sperlich et al. (2010)</td>
<td>5 weeks</td>
<td>Randomised cross-over study</td>
<td>5 sessions per week</td>
<td>5 sessions per week</td>
<td>$\dot{V}O_2^{peak}$ during cycling incremental step test</td>
<td>$100 \text{ m and 2,000 m TTP}$</td>
<td>Significant improvements in physiological performance and swimming performance</td>
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<tr>
<td></td>
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<td></td>
<td>5.5 km average TV per week</td>
<td>11.9 km average TV per week</td>
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<td>$50 \text{ m and 100 m CP}$</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>30 min HIT at 92% of PB time</td>
<td>60 minutes HVT at 85% of PB time</td>
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<td>27.4 km total TV</td>
<td>59.6 km total TV</td>
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<tr>
<td>Faude et al. (2008)</td>
<td>4 weeks</td>
<td>Randomised cross-over study</td>
<td>6 sessions per week</td>
<td>6 sessions per week</td>
<td>$BLA_{submax}$ during IST, post 100 m and 400 m TTP</td>
<td>$100 \text{ m and 400 m TTP}$</td>
<td>Significant increase in physiological performance ($BLA_{submax}$) for both groups</td>
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<td>40% ↓ in TV and 50% ↑ in HIT</td>
<td>30% ↑ in TV</td>
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<td></td>
<td>79.6 ± 13.7% of training at ≤ 101% IAT and 20.5 ± 6.7% of training at &gt; 101% IAT</td>
<td></td>
<td></td>
<td>No significant improvement in swimming performance for both groups</td>
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</tbody>
</table>
Kilen *et al.* (2014) | 12 weeks | Randomised controlled study | 5 – 7 sessions per week | 5 – 7 sessions per week | V̇O₂max during IST | 100 m TTP | No significant improvements in physiological performance and swimming performance for both groups |
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<tbody>
<tr>
<td>81.2 ± 7.4 km total TV</td>
<td>167.8 ± 23.7 km total TV</td>
<td>17.7 km average TV per week</td>
<td>35.3 km average TV per week</td>
<td>50% ↓ in TV and 100% ↑ in HIT</td>
<td>Regular training schedule</td>
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</table>

Kame *et al.* (1990) | 1 year | Controlled longitudinal study | 1 session per day | 2 sessions per day | V̇O₂peak during tethered IST | 50, 100, 200, 500, 1,000 and 1,650 yard CP | Significant improvement in physiological performance and swimming performance |
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<tr>
<td>1 hour HIT session</td>
<td>10,000 – 12,000 yards per day</td>
<td>3000 yards per day</td>
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Termin and Pendergast (2000) | 4 years | Uncontrolled longitudinal study | 4 Training Phases | No control/comparison group | V̇O₂max during IST | 100 and 200 yard CP | Significant improvements in physiological performance and swimming performance |
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<td>Phase 1: 2 – 3 weeks of low speed swimming</td>
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IAT.
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<th>Houston et al. (1981)</th>
<th>6.5 weeks</th>
<th>Non-randomised controlled study</th>
<th>≥ 4 sessions per week</th>
<th>≥ 4 sessions per week</th>
<th>VO$_{2\text{max}}$ during tethered swimming and treadmill running</th>
<th>23, 91 and 457 m TTP</th>
<th>Significant improvements in physiological performance in both groups</th>
<th>No significant improvements in swimming performance for both groups</th>
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<tr>
<td>Phase 2: 6 – 7 weeks of aerobic power intervals at 115 – 129% VO$_{2\text{max}}$</td>
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<td>Phase 3: 15 – 16 weeks of anaerobic intervals over 25 – 50 yards</td>
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<td>Phase 4: 3 weeks of 25 yard maximal velocity intervals</td>
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<tr>
<td>≥ 4 sessions per week</td>
<td>≥ 4 sessions per week</td>
<td>HIT consisted of 23 – 183 m intervals with rest durations of 70 – 140% of interval time.</td>
<td>MIT consisted of 183 – 457 m intervals with rest durations of 5 – 15% of interval time.</td>
<td>1,650 m average TV per session</td>
<td>3,200 m average TV per session</td>
<td>VO$_{2\text{max}}$ during tethered swimming and treadmill running</td>
<td>23, 91 and 457 m TTP</td>
<td>Significant improvements in physiological performance in both groups</td>
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<tr>
<td>Pugliese et al. (2015)</td>
<td>6 weeks</td>
<td>Interrupted time-series study</td>
<td>3 sessions per week</td>
<td>3 sessions per week</td>
<td>VO\textsubscript{2peak} during arm ergometer incremental test</td>
<td>100, 400 and 2,000 m TTP</td>
<td>Significant improvement in physiological performance and swimming performance for both groups</td>
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<td>50% ↓ in TV</td>
<td>30% ↑ in TV</td>
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<td></td>
<td>6,000 m average TV per week</td>
<td>12,000 m average TV per week</td>
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*↑ = increase; ↓ = decrease; TV = training volume; PB = personal best; VO\textsubscript{2peak} = peak rate of oxygen consumption; VO\textsubscript{2max} = maximal rate of oxygen consumption; BLa\textsubscript{submax} = velocity at blood lactate concentrations of 2 mM and 4 mM; BLa\textsubscript{peak} = peak rate of lactate accumulation post exercise; TTP = swimming time trial performance; CP = competitive swimming performance; IST = incremental swimming test; MIT = moderate intensity training; IAT = individual anaerobic threshold
Sperlich et al. (2010) scored 22/32 on the QI which was the highest score received out of the seven studies. Sperlich et al. (2010) compared a HIT and HVT intervention during a 5 week randomised cross-over study involving 26 youth swimmers. The HIT group experienced a 20.1% increase in BLa_peak (p < 0.01, effect size = 0.43) whereas the HVT group experienced a 30.1% decrease in BLa_peak (p < 0.01, effect size = 0.51). This increase in BLa_peak in the HIT group may lead to a greater contribution of anaerobic pathways therefore increasing power production while sprinting. In addition, Sperlich et al. (2010) found significant increases in cycling VO_2peak for the HIT group (+10.2%; effect size = 0.57) and HVT group (+8.5%; effect size = 0.46; p < 0.05). Swimming performance was also found to significantly improve during 50 and 100 m CP (+14.8%; p < 0.01; effect size = 0.48) and 2,000 m TTP (+2.8%; p = 0.04; effect size = 0.17) for the HIT group. The authors suggested that the 20.1% increase in BLa_peak may have influenced the 14.8% increase in 50 and 100 m CP for the HIT group. However, no significant changes were found to 100 m TTP following both interventions (p = 0.20) and the authors provided no reasons as to why this may have occurred. Despite this, the positive findings of the study indicate that a HIT intervention consisting of an average weekly training volume of 5.5 km was a more effective swimming training strategy for youth swimmers than a HVT intervention consisting of an average weekly training volume of 11.9 km.

A similar study by Faude et al. (2008) scored 19/32 on the QI and compared a HIT and HVT intervention during a 4 week randomised cross-over study involving 10 youth swimmers. The findings indicated that there was a significant increase in BLa_submax (velocity at a blood lactate concentration of 4 mM) in both the HIT and HVT group (p = 0.01), which indicates an improvement in aerobic endurance capacity in the participants. However there was no significant improvement in 100 and 400 m swimming performance for both groups. The HIT intervention comprised of 81.2 ± 7.4 km total training volume performed over 4 weeks and the HVT intervention comprised of 167.8 ± 23.7 km. Therefore the HIT group performed around 50% less training volume but had a similar training effect.

Kilen et al. (2014) investigated the effects of a HIT intervention during a 12 week randomised controlled study involving 41 elite swimmers. This was the only eligible study that involved national level elite swimmers and had the second highest QI score of 20/32. The findings indicated that the HIT intervention and control group’s training
resulted in no significant improvements to physiological performance (swimming $\dot{V}O_{2\text{max}}$) or swimming performance (100 and 200 m). The authors suggested that the swimmers had been performing HIT as part of their normal training program for a number of years and an upper limit may exist to the amount of HIT that can be applied and still yield further physiological adaptation. Despite this, the HIT intervention involved 50% less training volume per week (17.7 km) when compared to the control group who performed 35.3 km per week. Therefore, the HIT intervention was as successful as the control group’s training despite the 50% reduction in training volume per week.

Kame et al. (1990) investigated the effects of a HIT intervention during a 1 year controlled longitudinal study involving 17 university swimmers. The QI score for the study was 7/32, with the study scoring poorly on all five QI subscales. The HIT intervention resulted in a 20% increase in tethered swimming $\dot{V}O_{2\text{max}}$ measured from pre-season to post-season (3.12 ± 0.11 to 3.91 ± 0.1 L/min; p = 0.000). Improvements in 50 to 1,650 yard CP were greater than the improvements during the previous HVT season that was used as a control (2.6 ± 0.5% and 2.2 ± 0.7% respectively), however insufficient data was provided in the study to support this as a significant finding.

A similar study by Termin and Pendergast (2000) scored 12/32 on the QI and investigated the effects of a HIT intervention during a 4 year uncontrolled longitudinal study involving 22 university swimmers. The HIT intervention resulted in a 27% increase in $BLa_{\text{peak}}$ during the first year (p ≤ 0.05), however $BLa_{\text{peak}}$ was not found to significantly increase in year 2, 3 and 4. In addition, there was a 48% increase in swimming $\dot{V}O_{2\text{max}}$ (3.28 ± 0.12 to 4.86 ± 0.63 L/min), this was divided into increases of 20%, 9%, 8% and 5% from year 1 to year 4, respectively. The observed increases in physiological performance during the 4 year period were reflected in significant improvements to competitive performance. There was a 10% improvement in 100 yard (91.44 m) CP and an 8.3% improvement in 200 yard (182.88 m) CP over a 4 year period. The percentage improvements for the 100 yard (91.44 m) CP were 2, 4, 2 and 4%, for year 1 to 4 respectively. The percentage improvements for the 200 yard (182.88 m) CP were 1.9, 3.1, 2 and 1.3%, for years 1 to 4 respectively.

In addition, Houston et al. (1981) investigated the effects of a HIT and HVT intervention during a 6.5 week non-randomised controlled study involving 10 university
swimmers. The QI score for the study was 15/32. The findings indicated that there was significant increases in treadmill running $\dot{V}O_{2\text{max}}$ for the HIT group (+10.5%) and HVT group (+11.1%; $p < 0.05$), however there were no significant increases in tethered swimming $\dot{V}O_{2\text{max}}$ for both groups and the authors suggested that this finding was unexpected. There were no significant improvements in swimming performance for both groups.

Pugliese et al. (2015) scored 18/32 on the QI and investigated the effects of a HIT and HVT intervention during a 6 week interrupted time-series study involving 10 master swimmers. The HIT intervention resulted in a $12.4 \pm 5.3\%$ increase in $BL_{a_{\text{submax}}}$ (velocity at a blood lactate concentration of 4 mM) ($p = 0.004$) and 100 m TTP (+1.2 ± 0.8%; $p = 0.001$). However there were no significant changes in $\dot{V}O_{2\text{peak}}$, 400 m and 2,000 m TTP in the HIT group. In addition, the HVT group significantly improved $\dot{V}O_{2\text{peak}}$ (11.9 ± 4.9%; $p = 0.002$), 400 m TTP (+2.8 ± 1.8; $p = 0.002$) and 2,000 m TTP (+3.4 ± 2.9%; $p = 0.025$). The authors suggested that the lack of improvements in middle to long distance swimming performance (400 and 2,000 m) and $\dot{V}O_{2\text{peak}}$ during the HIT intervention was unexpected. However the authors suggested that the first training intervention (HVT) may have influenced the second intervention (HIT) as only 14 days separated both interventions, therefore this may be a limitation of the study.

3.5 Discussion

The purpose of this systematic review was to examine the extent and quality of the current research literature in order to determine the effects of HIT on physiological performance and swimming performance in competitive swimmers. The seven eligible studies that were found during this review extended to a wide range of competitive swimmers and included youth swimmers (Faude et al. 2008, Sperlich et al. 2010), elite swimmers (Kilen et al. 2014), university swimmers (Houston et al. 1981, Kame et al. 1990, Termin and Pendergast 2000) and master swimmers (Pugliese et al. 2015). The QI score of the seven studies had a mean of 16.1 points (range: 7 to 22) out of a maximum of 32 possible points. Six out of the 7 studies found that a HIT intervention resulted in significant improvements to physiological performance, both aerobic (Houston et al. 1981, Kame et al. 1990, Termin and Pendergast 2000, Faude et al. 2008, Sperlich et al. 2010, Pugliese et al. 2015) and anaerobic (Termin and Pendergast 2000, Sperlich et al. 2010). Four of the 7 studies found that HIT resulted in significant
improvements to swimming performance in events from 50 to 2,000 m (Kame et al. 1990, Termin and Pendergast 2000, Sperlich et al. 2010, Pugliese et al. 2015). None of the seven studies resulted in a reduction in physiological or swimming performance following a HIT intervention. Despite these positive findings there are limitations to a number of the studies.

Four studies were short in duration lasting between 4 and 6.5 weeks (Houston et al. 1981, Faude et al. 2008, Sperlich et al. 2010, Pugliese et al. 2015). The four studies involved a 40 – 50% decrease in normal training volume in the HIT group and it is logical to question if the additional rest during the 4 to 6.5 week study period may have influenced results in the HIT group. This may not be dissimilar to the concept of tapering prior to a swimming competition which has been found to enhance swimming performance (Trinity et al. 2006, Papoti et al. 2007, Trinity et al. 2008). Tapering is a common practice in the final weeks prior to a major competition and involves reducing training volume with or without increased training intensity. The aim of a swimming taper is to enhance recovery from high training volumes and thus competitive performance. Trinity et al. (2006) investigated the effects of a 3 week competitive taper in 24 male elite swimmers that were separated into two groups. The first group reduced training volume from an average of 45,000 m per week to 20,000 m per week over a 3 week period and this resulted in a 4.4% increase in swim performance velocity (p < 0.05). The second group reduced training volume from an average of 55,000 m per week to 25,000 m per week over a 3 week period and this resulted in a 4.7% increase in swim performance velocity (p < 0.05). Similarly, a second study by Trinity et al. (2008) investigated the effects of two different types of 3 week tapers in seven female university swimmers over two seasons. The tapers both involved a reduction in training volume from 45,000 – 55,000 m per week to 20,000 m week in combination with different volumes of HIT. The first taper consisted of HIT for 15 to 20% of the total training load and the second taper consisted of HIT for 30 to 32% of the total training load. The first taper resulted in resulted in a 5.3% improvement in swim performance velocity (p = 0.005). The second taper resulted in a 2.7% improvement in swim performance velocity (p < 0.001). A reduction in training volume over a tapering period appears to enhance swimming performance therefore the results of short duration HIT interventions should be considered with caution. Two longitudinal studies of 1 year and 4 years duration were conducted but both studies had the lowest QI scores of the review (7/32 and 12/32) due to numerous methodological flaws related to all five subscales on
the QI (Kame et al. 1990, Termin and Pendergast 2000). It was clear that physiological performance and swimming performance did significantly improve in both studies however due to the lack of an appropriate control group in both studies, it is logical to question if similar or greater improvements to performance could have occurred during a HVT intervention of the same duration.

The exercise modalities used to assess $\dot{V}O_2$peak and $\dot{V}O_2$max in two studies are questionable (Houston et al. 1981, Sperlich et al. 2010). Sperlich et al. (2010) used a bicycle ergometer to assess $\dot{V}O_2$peak which may not entirely reflect swimming specific aerobic capacity and is therefore a limitation to the study. This was acknowledged by the authors as previous pilot testing had been performed through assessing $\dot{V}O_2$peak in a swimming flume but this proved difficult to implement due to the age and experience of the participants (10.5 ± 1.4 years). Houston et al. (1981) used a treadmill to assess $\dot{V}O_2$max which again may not entirely reflect swimming specific aerobic capacity, however tethered swimming was also used to assess $\dot{V}O_2$max. The challenges of physiological testing within an aquatic environment and of performing intervention studies that involve altering a coach’s training programme must be acknowledged while considering these limitations. Despite this, none of the seven studies resulted in a reduction in physiological or swimming performance following a HIT intervention and many of the studies resulted in a significant improvement to performance. This is an interesting finding and appears to suggest that traditional HVT may not be the only training methodology for competitive swimmers, which has increasingly been suggested by swimming coaches who have had success using HIT swimming programmes (Stott 2012a, Stott 2014, Carlile 2015, Salo 2015, Goldsmith 2016).

Traditional HVT methodologies for competitive swimmers have been investigated and the findings do not appear to provide any strong evidence in support of this approach. Costill et al. (1991) investigated the effects of a 6 week period of increased training volume on physiological adaptations and swimming performance in 24 university swimmers. The 6 week period involved a group that trained once per day with an mean training volume of 4,950 m per day (short group) and another group that gradually increased the training volume to 9,435 m per day, spread over two sessions per day (long group). The results indicated that the additional training volume performed by the long group did not enhance their aerobic or anaerobic capacities over the short group ($p < 0.05$). A similar study by Ryan et al. (1990) investigated the effects of increased
training volume on BLa_{submax} (velocity at a blood lactate concentration of 4 mM) during a 5 month study involving 14 elite swimmers. The results indicated that when training volume was increased from 34,000 yards (31,090 m) per week to 54,000 yards (49,378 m) per week during the first month of the study, BLa_{submax} increased by 15% (p < 0.05). However further increases in training volume up to a maximum of 72,000 yards (65,837 m) per week over the remaining 4 months of the study, resulted in no significant improvement in BLa_{submax}. The authors concluded that increasing training volume above 54,000 yards (49,378 m) per week had no effect on BLa_{submax}.

There are concerns that high volumes of training may increase the risk of early specialisation in youth athletes (Moesch et al. 2011, Jayanthi et al. 2013, Myer et al. 2015a, Myer et al. 2015b). Early specialisation refers to the concept of a child participating in year-round intensive training within a single sport at the exclusion of others (Wiersma 2000) and can potentially have many negative consequences such as an increased risk of injury (Jayanthi et al. 2013, Jayanthi et al. 2015, Myer et al. 2015a); overtraining and early dropout (Carter and Micheli 2011, Jayanthi et al. 2013, Myer et al. 2015a); reducing the individual’s all round motor skill development (Mostafavifar et al. 2013, Lloyd et al. 2015) and reduced performance later in their athletic career (Fransen et al. 2012, Bridge and Toms 2013). A Long Term Athlete Development (LTAD) model for swimmers has recommended that males aged 9 – 12 and females aged 8 – 11 should be performing 8,000 – 16,000 m over 4 – 6 pool sessions per week (Lang and Light 2010). The LTAD model further suggested that males aged 12 – 15 and females aged 11 – 14 should perform 24,000 – 32,000 m over 6 – 12 sessions per week. Similar training practices for youth swimmers are evident in the literature (Hibberd and Myers 2013, Krabak et al. 2013). It is highly questionable how youth swimmers could commit to these training recommendations without early specialisation within the sport. Two studies in this systematic review involving youth swimmers found that HIT interventions comprising of 40 – 50% less training volume for a duration of 4 – 5 weeks significantly enhanced physiological performance and swimming performance (Faude et al. 2008, Sperlich et al. 2010). Clearly more research is needed in this area due to the risks associated with early specialisation.
3.6 Conclusion

Swimming performance has been shown to be determined by a number of different anthropometrical, physiological and biomechanical parameters (Jürimäe et al. 2007, Lätt et al. 2010, Vitor and Böhme 2010). Biomechanical parameters have been suggested as one of the best determinants of swimming performance (Jürimäe et al. 2007, Lätt et al. 2010, Vitor and Böhme 2010). Swimming coaches suggest that large amounts of practice are needed to develop swimming technique (Greyson et al. 2010) and this is perhaps one of the incentives for HVT, particularly in youth swimmers who need time to develop their technical capacity. Despite this, investigating the effects of HIT on biomechanical parameters related to swimming technique was outside the scope of this review due to a lack of reporting in a number of the eligible studies (Houston et al. 1981, Sperlich et al. 2010, Kilen et al. 2014, Pugliese et al. 2015).

In future interventions, biomechanical parameters should be investigated in order to establish the effects of HIT and/or HVT on swimming technique. A particular focus should be placed on investigating the effects of HIT on competitive swimmers who already have an established technical capacity. This systematic review should be used as a guideline by swimming coaches and researchers in the design of future HIT interventions. Controlled studies of a longer duration are needed (≥ 12 weeks) that include a definite decrease in training volume while increasing training intensity and assessing any potential effects using outcome measures of physiological, biomechanical and swimming performance.
Chapter 4: Study 2 – Quality versus Quantity Debate in Swimming: Perceptions and Training Practices of Expert Swimming Coaches

4.1 Abstract

**Purpose:** The debate over low-volume, high-intensity training (HIT) versus high-volume, low-intensity training (HVT), commonly known as Quality versus Quantity respectively, is a frequent topic of discussion among swimming coaches and academics. The aim of this study was to explore expert coaches’ perceptions of quality and quantity coaching philosophies in competitive swimming and to investigate their current training practices. **Methods:** A purposeful sample of 11 expert swimming coaches was recruited for this study. The study was a mixed methods design and involved each coach participating in 1 semi-structured interview and completing 1 closed-ended questionnaire. **Results:** The main findings of this study were that coaches felt quality training programmes would lead to short term results for youth swimmers but were in many cases more appropriate for senior swimmers. The coaches suggested that quantity training programmes build an aerobic base for youth swimmers, promote technical development through a focus on slower swimming and help to enhance recovery from training or competition. However the coaches continuously suggested that quantity training programmes must be performed with good technique and they felt this was a misunderstood element. **Conclusion:** This study was a critical step towards gaining a richer and broader understanding on the debate over Quality versus Quantity from expert swimming coaches’ perspective which was not currently available in the research literature.
4.2 Introduction

The relevance of HVT to the physiological requirements of many swimming events is a long standing topic of discussion in the scientific literature (Aspenes and Karlsen 2012). One of the earliest researchers on the topic, David Costill, summarises this by stating “it is difficult to understand how swimming at speeds that are markedly slower than competitive pace for 3 to 4 hours per day will prepare the swimmer for the supramaximal efforts of competition” (Costill et al. 1991). In the swimming community, this has been referred to as the debate over “Quality vs Quantity” (Maglischo 2003b, Salo and Riewald 2008b). On the quality or HIT side of the debate there is the suggestion that swimmers can reduce training mileage with no loss of endurance capacity if they perform their swimming intervals at faster speeds, whereas the quantity or HVT side suggest that more swimming mileage will produce greater endurance capacity and thus faster swimming times.

A recently published systematic review by Nugent et al. (2016) investigated the effects of HIT, otherwise known as quality training, on performance in competitive swimmers from youth to masters level. Seven studies met the inclusion criteria for the review. The studies ranged in duration from 4 weeks to 4 years. Six out of the 7 studies found that a HIT intervention resulted in significant improvements to outcome measures of physiological performance. Four of the 7 studies found that HIT resulted in significant improvements in swimming performance, whilst none of the seven studies resulted in a reduction in physiological or swimming performance. Despite some of the positive reported findings of HIT studies in swimming, the applications of these findings to the long-term development of a youth swimmer may be limited as a number of the current studies are short in duration at only 4 to 6 weeks. In addition, youth swimming performance has been found to not be entirely determined by physiological variables but is more multifactorial in nature involving a complex interplay of kinematics, efficiency and hydrodynamics (Morais et al. 2015, Morais et al. 2017). Therefore, future HIT interventions should aim to account for some of these variables.

In the swimming community, the recent success of competitive swimmers who train using a derivative of HIT called Ultra-Short Race-Pace Training (USRPT) has further fuelled this debate (Stott 2014, Beliaev 2015, Goldsmith 2016). USRPT is defined as high intensity swimming in sets that match the best achieved velocities of individuals’ races and consists of a high number of repetitions over short distances with brief rests,
generally no longer than 20 seconds (Rushall 2011). Competitive swimmers who advocate USRPT have been reported to average around 9 – 11 km per week (Stott 2014). This is in stark contrast to the more traditional 38 – 44 km per week for youth swimmers reported by Hibberd and Myers (2013) and the 54 ± 19 km per week reported for elite swimmers (Pyne et al. 2001).

Concerns over long term athlete development (LTAD) models that advocate HVT for youth swimmers have been previously expressed by English swimming coaches (Lang and Light 2010). The main concern expressed by the swimming coaches was that the LTAD model had an overemphasis on training volume leading to the neglect of technique. A subsequent commentary article by Greyson et al. (2010) suggested that developing the aerobic energy system in swimmers, primarily through the use of HVT, is crucial in order to target the optimal window of opportunity for aerobic development as proposed in the LTAD model (Balyi and Hamilton 2004). However, the windows of opportunity within the LTAD model are largely theoretical and lack supporting longitudinal research (Lloyd and Oliver 2012). Despite this, anecdotal evidence suggests many of the top swimming nationals in the world advocate HVT for youth swimmers and their success at Olympic level is evident.

The emerging evidence in the literature and within the swimming community on the debate over HIT vs HVT, commonly known as Quality vs Quantity, provides a strong rationale to conduct this study. The experiential knowledge of expert coaches has been suggested to play a useful role in enhancing the understanding of sports performance (Greenwood et al. 2012). This experiential knowledge is often based on day to day practice and performance experiences throughout a coaches’ career and may provide rich information on a topic (Greenwood et al. 2012). Therefore, the aim of this study was to explore expert swimming coaches’ experiential knowledge of the impact of quality and quantity coaching philosophies on swimming performance and to investigate their current training practices.
4.3 Methods

4.3.1 Participants
The participants in this study were 11 expert swimming coaches: sex (10 male, 1 female), ages ranged from 35 to 60 years (47.6 ± 7.3 years), swim coaching experience ranged from 16 to 40 years (27.4 ± 8.7 years), education (nine coaches were educated to 3rd level, two coaches were educated to 2nd level) and employment (five part-time swim coaches, six full-time swim coaches). In addition, the coaches were personally responsible for coaching swimmers to the following major international events: three coaches had coached multiple swimmers to an Olympic Games, one to a Paralympic Games, four to a World Senior Championships, two to a European Senior Championships and one to a World Junior Championships.

4.3.2 Research Design
The study was a mixed methods design and involved the coaches partaking in one semi-structured interview and completing one closed-ended questionnaire. A mixed methods design was appropriate to address the research aim as the combination of qualitative and quantitative data may allow for a better understanding of a phenomenon and enhances the overall strength of a research study (Creswell 2013).

4.3.3 Procedures
Approval to conduct this study was provided by the University of Limerick Ethics Committee. Prior to participating, all coaches were informed of the purpose of the study, provided written informed consent and were ensured of confidentiality (see Appendix 1 and 2). The coaches were classified as expert or top level in their country based on three criteria related to experience, achievement and qualification which have been used to define expert coaches in previous studies (Thompson et al. 2009). The inclusion criteria for expert coaches was (a) they held a Level 3 swim coaching certification, the highest available coaching award from their national governing body; (b) they had a minimum of 10 years swim coaching experience; (c) they had coached at least two international level swimmers. A purposeful sample of expert coaches was recruited using a snowball sampling strategy in order to identify the most productive respondents to enhance the depth and richness of information gathered (Patton 2015). The snowball sampling strategy was initiated by contacting two expert swimming coaches from different clubs. The coaches were informed of the inclusion criteria for the
study and were asked to recommend any additional contacts that could provide different and/or confirming perspectives on the research topic. Subsequent interviews resulted in additional contacts, thus fulfilling the requirements of a snowball sampling strategy as defined by Patton (2015).

A semi-structured interview was used to provide the basis for an exploration of the participants’ experiences, opinions and to elicit truly open ended responses (Patton 2015). The interviews ranged in duration from 22 to 55 minutes (mean = 39 minutes). An interview topic guide was designed specifically for this study and was pilot tested on two expert swimming coaches. As suggested by Mayan (2009), the interview topic guide was split into three main sections: the introduction (e.g. “Tell me how you started out as a swimming coach”), the formal portion (e.g. “Based on your coaching experience so far, what are your opinions of a quality based coaching philosophy?” and “Based on your coaching experience so far, what are your opinions on a quantity based coaching philosophy?”) and conclusion (“Is there anything else you would like to add to the topics we discussed during the interview?”). Probes were used at various stages throughout the interview to increase the depth and complexity of participants’ responses (Patton 2015). Prior to the formal portion of the interview, a definition of a quality and quantity based coaching philosophy, as described by Maglischo (2003b) was provided.

Following the semi-structured interview, each coach completed a closed-ended questionnaire that was designed to gather information about the coach’s current training practices across all of the developmental stages of a competitive swimmer. The questionnaire was adapted from research by Krabak et al. (2013) and was pilot tested with two expert swimming coaches in order to establish validity (see Appendix 3). The Long Term Athlete Development (LTAD) model that is currently in use by the national governing body was suggested as the most practical method to categorise the distinct phases in the development of competitive swimmers within this cultural context (Swim Ireland Aquatic Pathway' 2007). The questionnaire was subsequently divided into four sections which were specific to the distinct phases within the LTAD model: Swim Skills Stage (Males 9 – 12 years and Females 8 – 11 years), Training to Train Stage (Males 12 – 15 years and Females 11 – 14 years), Training to Compete Stage (Males 15 – 18 years and Females 14 – 16 years) and Training to Win Stage (Males 18+ years and Females 16+ years). Each section contained four questions that were related to training frequency, training duration, training distance and energy systems.
4.3.4 Data Analysis

Interviews were digitally recorded and transcribed verbatim by the first author. The interviews were imported into NVivo 10 (QSR International Pty, Ltd, 2012) for data analysis. A thematic analysis was conducted as outlined by Braun and Clarke (2006). The first phase involved familiarisation with the data in order to establish some initial ideas. The second phase involved generating codes which are defined as meaningful units of the text. The third phase involved sorting the codes into potential themes that reflect the overall content and meaning of the data. The final phase involved further reviewing and defining of the themes. The questionnaire data was analysed using descriptive statistics (frequency of coach responses) and is summarised in Tables 4.1 and 4.2.

A number of procedures were employed to enhance the trustworthiness of the findings. Firstly, the interviews were conducted by the lead author who had previous swimming experience. This helped in establishing rapport and may have encouraged participants to provide more open and accurate answers. Secondly, data triangulation was achieved by using multiple sources (e.g. interview and questionnaire) which has been suggested to allow better understanding of a phenomenon and strengthen the findings of a study (Creswell 2013). In addition, participants were sent their interview transcript and were asked to confirm the accuracy of the information transcribed.

4.4 Results

The main themes that emerged from the interview findings were: (i) Quality programmes lead to short term results; (ii) Quality programmes are for senior swimmers; (iii) Building the aerobic base; (iv) The importance of slow swimming; (v) Break Point Volume. All of the themes are discussed and illustrated by representative quotes from the participants. Pseudonyms are used throughout to protect the identities of those provided in the text.

**Theme 1: Quality programmes lead to short-term results.** The majority of coaches consistently expressed concerns that quality programmes lead to short-term results for youth swimmers. In many cases, they described quality programmes for youth swimmers as a “quick fix”, “detrimental to long-term development” and “not sustainable”. This coach stated: “There is a massive argument at the minute here in Ireland because you have swimmers who are doing a quality based programme, but they
are getting results. Are those results going to be further down the road? I can't tell you and I'd say the coach doesn't know either.” (Coach #4). Concerns around the long-term development of youth swimmers who train using quality based programmes were further expressed by another coach:

“So if I look at a lot of successful youth swimmers that were from particular types of programmes, they usually weren’t volume programmes they were usually ones that were very intense and quality based. But they got to a particular point and they could never get past. That’s where my philosophy got really based. What I feel is that you’ve got to take a step back and say, ‘ok we could make them fast in a year or two but how is that going to affect them in 4 or 5 years time?’. I think that's the real developmental bit.” (Coach #9)

**Theme 2: Quality programmes are for senior swimmers.** Many of the coaches suggested that quality programmes were more appropriate for senior swimmers. The USA swim coach, David Salo, was regularly quoted as one of the influencing factors behind this belief pattern. David Salo is one of the most widely known and successful proponents of a quality based training programme (Salo and Riewald 2008b). This coach highlighted the benefits of a quality training programme for distance swimmers:

“Over the years I’ve known coaches that have believed mileage, mileage, mileage makes swimmers better. I don't believe in that because mileage will make you fitter, but it won't make you faster. So what I mean for example is I've Jim (multiple senior distance record holder), he swims much better on a 55 k or below 55 k a week quality programme than he would when he was doing 70 k a week because he was always tired. He needs the race pace work to get better” (Coach #3)

One coach appeared to have strong views on the benefits of a quality training programme for sprint, middle distance and distance swimmers. This coach worked primarily with senior swimmers:

“We only train quality. There is this schism, there are people who believe it is volume, still believe its volume. I don’t. I don't believe it's volume anymore I believe it's speed. I don't believe swimming to be an endurance sport which most people will tell you it is. They will go, ‘you need all the milleage’. Now I have to say here that we only have
swimmers up to 200 metres at the moment so we race 50 to 200 metres. So it suits them to do nothing but speed so effectively we could be termed a sprint group, running a sprint programme. If I had distance swimmers, I still probably wouldn’t go down the serious volume route. I don't believe it. I don't believe it at all”. (Coach #5)

Following further probing into the reasoning behind these views, the coach stated:

“I think neuromuscular is the issue. The actual neural pathways that are fired. I think we are very obsessed by the physiology. Talk to a lot of coaches, ‘oh yea he is doing twenty 100s on 1.20 holding threshold etc etc etc.’ Yea but he's now travelling at 1.09 for 2 hours. He has to race at 49 seconds, do you think the 2 hours neurologically, do you think that firing pattern is what he is going to use? They are different pathways, firing different pathways. So I think in that senses we have got lost and we've started doing too much volume.” (Coach #5)

**Theme 3: Building the aerobic base.** Nearly all of the coaches emphasised the importance of quantity training in building an aerobic base for youth swimmers. The process of building an aerobic base was described as “laying the foundations”, “building the engine” and “building the pyramid layer by layer”. The coaches consistently suggested that building an aerobic base was necessary in order to lay the foundations for success as an international swimmer. The coaches believed this was necessary for all types of youth swimmers regardless of their natural tendency towards sprint or distance events:

“My philosophy around that is simple and it's to do with developmental stages. If you want to build an engine you are building the heart, the lungs and the energy transport system. That's an endurance base. You want to build a system to be used later on whether you’re a sprinter with fast twitch fibres or not. If you look at a lot of successful swimmers and forget the science behind it, where do they come from? They usually come from somewhere where they have done not a huge volume but a reasonable volume consistently at a young age but done very technically well. Then when they are older they have built that system, that's my philosophy. So they have built the base for a future date and they will be able to use that.” (Coach #9)
A number of the coaches consistently suggested that building an aerobic base in youth swimmers will help to enhance recovery from training and competition. The coaches felt this was a vital component that many people do not understand:

“People say ‘well you guys train so much in swimming but you only race for a minute in a 100.’ Yea but we don't just go and do one 100 you know if you're a breaststroker for example and you were at the European Championships last week, you would have raced over 7 days. If you were a good breaststroker you would have done the 50 - the heats and semi-final. You would have done the 100 - heats, semi-final. You would have done the 200 - heats, semi-final. And you might have been on the medley relay - heats and final. So you know that's 11 races over 7 days. If you haven't got some good aerobic background in you then you just won't make it.” (Coach #8)

One coach highlighted how they felt a quantity training programme during the developmental years of an Olympic sprint swimmer may have influenced the swimmer’s ability to recover from sprint training when she was a senior swimmer:

“If I took somebody like this girl that I used to coach - Janet who was a 100 and 200 freestyler in the Olympics. When she was an age group swimmer she was able to swim very, very efficiently at 200, 400, 800 and 1,500 metres. As she got older she was definately a sprinter. She could just stand up on the block and always be fast. So it was just a natural tendency for her to be fast. So what I felt was the work that we had done with her as an age grouper was always money in the bank for her. So we were able to put more focus on her speed work and so on as she became an older athlete. When she went on to college swimming the coach always commented that her fitness level was always so much better than anyone else and that allowed her to do more sprints and recover a lot quicker.” (Coach #11)

In contrast to this, there were a small number of coaches who expressed doubts around the common methods of building an aerobic base. One coach stated:

“There is that obsession that if you don't put in the so called aerobic base they will never be world class swimmers. Well I would question what is the aerobic base? How much of it do you need? And are there other ways of getting there? Besides just massive volume because that does work. If you throw enough at it, it will work. But what if there
was other ways that get the children socially engaged in the sport and maybe it wasn't as brutal to them because it is. You know it's a hard sport to sell when you got to get up at 4 and 5 am compared to say football or Gaelic football or rowing? I think you are destroying the children.” (Coach #5)

Theme 4: The importance of slow swimming. The majority of coaches believed that swimming slowly was vital to building good technique: “I think sometimes you've got to learn to swim slowly. You've got to learn to be able to swim technically well, slow, before you can swim it fast” (Coach #4). Another coach suggested that swimming is not natural to humans and that swimming slowly for long periods of time will build better technique for faster swimming:

“I look at swimming as being one of the sports that is not natural to us. So one of the things that I've always felt about swimming was the fact that because it's so technique based you have to be in a place where you're relaxed and your technique becomes efficient so efficiency through good technique. And how do we get more efficient? By being able to apply that technique over longer periods of swimming and being able to swim at a slower pace and not always focus on swimming at a very fast pace. Because what happens is when you swim at a very fast pace the first thing that goes is your technique, your technique falls apart because you are unable to maintain that technique.” (Coach #11)

One coach suggested that the focus on slower swimming in quantity based training programmes provides better opportunities for technical development than a quality training programme due to the swimmer completing higher repetitions of a skill:

“We are a technique limited sport. You can only be as good as your skills are going to develop. If you look at it, my understanding from reading the current literature out there on skill acquisition is that you have to have a high level of repetitions of something before you turn a concise act into an unconcise habit. So there is great value from a technical point of view in having a programme that covers higher volumes at lower intensities because you have more opportunities to get a higher amount of correct repetitions.” (Coach #7)

However, a number of coaches suggested that it was still important for youth swimmers
to practice swimming fast but this should be conducted using, “Short sprints for less than 10 seconds. There's no lactic acid building up and all that. HVO’s...high velocity overloads, I believe in doing that with them.” (Coach #3)

**Theme 5: Break Point Volume.** Break Point Volume is a theory that was consistently mentioned throughout the interviews. Break Point Volume is a theory proposed by Bill Sweetenham, coach of multiple Olympic medallists in swimming and is defined as an optimal training volume performed at an optimal skill level that is achieved through a maximum number of training sessions at controlled intensities, which are predominantly aerobic, during maturation (Sweetenham 2006). The theory outlines that swimming training programmes should build slowly and steadily towards a specific training volume that is achieved between 13 and 15 years of age (Sweetenham 2006). The recommendations for achieving this specific training volume are 2,000 to 2,500 km of swimming spread over 42 to 46 weeks of the year and includes about 400 training sessions (Sweetenham 2006).

Many of the coaches suggested that Break Point Volume theory was one of the main guiding principles within their coaching philosophy however many had trouble achieving the recommendations:

“So my programme has always been pitched around Bill Swettenham’s Break Point Volume theories which are 2.2 million metres a year for developmental athletes for at least 4 to 5 years. So we tried to put that in place and I can show you where I think we delivered that over the course of a year which is an average of 45 to 50 k a week but the number of athletes who do it would always be quite small because things get in the way, life gets in the way.” (Coach #6)

A number of coaches suggested that the training recommendations within the Break Point Volume theory should be conducted while taking the individual swimmer’s lifestyle into account: “You've got to be careful with that term and we have kids coming through and some can't do as much as others and finding that is part of individual trainability. We're not forcing kids to do more than they can cope with.” (Coach #8).

A summary of the results from the closed-ended questionnaires are provided in Table 4.1 and 4.2. All 11 coaches completed the questionnaire. The number of coach
responses to each individual question is provided in the tables. Table 4.1 displays the average swimming hours, average swimming training sessions and the average number of metres completed per week for each LTAD stage. Table 4.2 displays the energy systems order of importance for each LTAD stage.

Table 4.1 Average hours, sessions and metres of swimming per week for each LTAD stage (number of coach responses)

<table>
<thead>
<tr>
<th>Hours per week</th>
<th>Swim skills*&lt;br&gt;(M 9 – 12, F 8 – 11yrs)</th>
<th>Training to train*&lt;br&gt;(M 12 – 15, F 11 – 14yrs)</th>
<th>Training to compete*&lt;br&gt;(M 15 – 18, F 14 – 16yrs)</th>
<th>Training to win*&lt;br&gt;(M 18+, F 16+)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 5 hours</td>
<td>3</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5 – 10 hours</td>
<td>8</td>
<td>3</td>
<td>-</td>
<td>-</td>
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<tr>
<td>11 – 15 hours</td>
<td>-</td>
<td>8</td>
<td>6</td>
<td>2</td>
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<tr>
<td>16 – 20 hours</td>
<td>-</td>
<td>-</td>
<td>5</td>
<td>8</td>
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<tr>
<td>21 – 25 hours</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>&gt; 25 hours</td>
<td>-</td>
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</tr>
<tr>
<td>Sessions per week&lt;br&gt;</td>
<td></td>
<td></td>
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</tr>
<tr>
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<tr>
<td>3 – 5 sessions</td>
<td>7</td>
<td>3</td>
<td>-</td>
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<tr>
<td>6 – 8 sessions</td>
<td>2</td>
<td>6</td>
<td>5</td>
<td>-</td>
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<tr>
<td>9 – 11 sessions</td>
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<td>&gt; 14 sessions</td>
<td>-</td>
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<tr>
<td>Metres per week&lt;br&gt;</td>
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<td>&lt; 5,000 metres</td>
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<td>5,001 – 10,000 metres</td>
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</tr>
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<td>2</td>
<td>-</td>
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<td>&gt; 70,000 metres</td>
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</table>

*Swim Skills (M 9 – 12, F 8 – 11yrs), Training to Train (M 12 – 15, F 11 – 14yrs), Training to Compete (M 15 – 18, F 14 – 16yrs), Training to Win (M 18+, F 16+)
Table 4.2 Order of importance for training the different energy systems during each LTAD stage (number of coach responses).

<table>
<thead>
<tr>
<th>Order of importance*</th>
<th>Swim skills*</th>
<th>Training to train*</th>
<th>Training to compete*</th>
<th>Training to win*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Aerobic energy system (11)</td>
<td>Aerobic energy system (11)</td>
<td>Aerobic energy system (8)</td>
<td>Aerobic energy system (6)</td>
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<td>2</td>
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<td>Aerobic energy system (3)</td>
<td>Aerobic energy system (4)</td>
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<tr>
<td></td>
<td>ATP-CP energy system (9)</td>
<td>ATP-CP energy system (6)</td>
<td>ATP-CP energy system (4)</td>
<td>ATP-CP energy system (3)</td>
</tr>
<tr>
<td>3</td>
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<td>Anaerobic energy system (6)</td>
<td>Anaerobic energy system (4)</td>
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<td>ATP-CP energy system (5)</td>
<td>ATP-CP energy system (7)</td>
<td>ATP-CP energy system (8)</td>
</tr>
</tbody>
</table>

*Order of importance (1 = most important, 3 = least important). *Swim Skills (M 9 – 12, F 8 – 11yrs), Training to Train (M 12 – 15, F 11 – 14yrs), Training to Compete (M 15 – 18, F 14 – 16yrs), Training to Win (M 18+, F 16+). *Aerobic energy system (Zone 1 and 2); Anaerobic energy system (Zone 3 and 4); ATP-CP Energy System (Zone 5) (Sweetenham and Atkinson 2003)
4.5 Discussion

The aim of this mixed methods study was to explore expert swimming coaches’ perceptions of quality and quantity coaching philosophies and to investigate their current training practices. This study advances the current coaching and sports science literature by exploring the experiential knowledge of a cohort of expert Irish swimming coaches. This experiential knowledge is often based on day to day practice and performance experiences throughout a coaches’ career (Greenwood et al. 2012). In this study, the expert swimming coaches’ experiential knowledge has helped to provide rich information on the quality vs quantity debate. The main themes that emerged from the interview findings were: (i) Quality programmes lead to short term results; (ii) Quality programmes are for senior swimmers; (iii) Building the aerobic base; (iv) The importance of slow swimming; (v) Break Point Volume. The interview findings can be supported through data triangulation using the results of the questionnaire, thus fulfilling the requirements of a mixed methods study as outlined by Creswell (2013). In addition, further data triangulation of the interview findings was conducted using the current literature.

**Theme 1: Quality programmes lead to short-term results.** The interview findings indicated the wide held perception that quality programmes may lead to short-term results in youth swimmers. The coaches suggested that a quantity coaching philosophy that focuses on higher volume swimming at lower aerobic intensities is needed. This finding appears to be evident in Table 2 where 100% of the coaches surveyed (n = 11) indicated that the aerobic energy system or training zone 1 and 2 in Sweetenham and Atkinson (2003) was the most important energy system to develop during the Swim Skills (Males 9 – 12 years and Females 8 – 11 years) and Training to Train stage (Males 12 – 15 years and Females 11 – 14 years) of development.

A small number of coaches interviewed indicated that short sprints of less than 10 seconds were important for youth swimmers and called these “high velocity overloads” or HVO’s. The importance of these short sprints appears to be evident in Table 2 where 9 out of 11 (81.8%) coaches indicated that the ATP-CP energy system or training zone 5 in Sweetenham and Atkinson (2003) was the second most important energy system to develop during the Swim Skills stage (Males 9 – 12 years and Females 8 – 11 years) of development.
A recent systematic review by Nugent et al. (2016) found only two studies involving quality or HIT interventions in youth swimmers. The studies involved a 40 – 50% reduction in training volume for a duration of 4 – 5 weeks and resulted in significant improvements in physiological performance (\( \dot{V}O_{2\text{max}} \), sub-maximal lactate indices and peak lactate indices) and swimming performance (Faude et al. 2008, Sperlich et al. 2010). However the 4 – 5 week duration of both studies is short in duration and therefore the long term applications of this type of training intervention remain unknown. An expert commentary article by Greyson et al. (2010) advises against too much anaerobic training at a young age as it will result in the reduction in a swimmer’s potential to be a successful international swimmer. Greyson et al. (2010) also suggests that swimming technique is best developed during aerobic swimming as technique is difficult to maintain during anaerobic swimming.

**Theme 2: Quality programmes are for senior swimmers.** The interview findings indicated that quality programmes may be more appropriate for senior swimmers. In support of this, many of the coaches suggested that their philosophies were influenced by the theory of Break Point Volume which suggests that youth swimmers should focus on quantity training during maturation with quality training, that is more anaerobic in nature, becoming more prominent as a swimmer reaches full maturation (Sweetenham 2006). Table 4.2 displays a trend towards Break Point Volume theory as highlighted by an evident shift towards developing the anaerobic energy system or training zone 3 and 4 in Sweetenham and Atkinson (2003) during the Training to Win stage (Males 18+ years and Females 16+ years) with 5 out of 11 coaches (45.4%) indicating that the anaerobic energy system was the most important energy system to develop at this stage.

The systematic review by Nugent et al. (2016) identified four HIT studies that were conducted on senior swimmers (Houston et al. 1981, Kame et al. 1990, Termin and Pendergast 2000, Kilen et al. 2014). The studies ranged in duration from 6.5 weeks to 4 years. Three of the studies resulted in significant increases in physiological performance (\( \dot{V}O_{2\text{max}}, \dot{V}O_{2\text{peak}} \) and peak lactate indices) and swimming performance. None of the four studies resulted in a reduction in physiological or swimming performance following a HIT intervention. Despite these positive findings the exercise testing modalities (Houston et al. 1981), short duration (Houston et al. 1981), and lack of an appropriate control group (Kame et al. 1990, Termin and Pendergast 2000) in many of the studies are a concern.
**Theme 3: Building the aerobic base.** The interview findings indicated that building the aerobic base is vital for youth swimmers. These findings are evident across Table 4.1 and 4.2. Table 4.1 highlights the average training hours, number of sessions and number of metres completed per week. Table 4.1 displays a clear and linear increase in training hours, number of sessions and number of metres completed per week from the Swim Skills (Males 9 – 12 years and Females 8 – 11 years) to the Training to Win stage (Males 18+ years and Females 16+ years) of development. For example, 4 out of 11 coaches (36.4%) indicated that 10 – 15,000 metres per week was their average training distance prescribed during the Swim Skills stage (Males 9 – 12 years and Females 8 – 11 years) while 5 out of 11 coaches (45.4%) indicated that 50 – 50,000 m per week was their average training distance prescribed during the Training to Win stage (Males 18+ years and Females 16+ years) of development.

Table 4.2 provides further support to the theme of “building the aerobic base” as 100% of the coaches surveyed (n = 11) indicated that the aerobic energy system or training zone 1 and 2 in Sweetenham and Atkinson (2003) was the most important energy system to develop during the Swim Skills (Males 9 – 12 years and Females 8 – 11 years) and Training to Train stage (Males 12 – 15 years and Females 11 – 14 years) of development.

Nearly all of the coaches in our study continuously emphasised the importance of building the aerobic base with good technique as many of the coaches felt that people misunderstood this aspect and that in many cases quantity programmes, which build an aerobic base, could lead to poor technique. This is a similar theme to those previously reported by Lang and Light (2010) who explored English swimming coaches’ views on the LTAD model outlined by the Amateur Swimming Association. The main findings of the Lang and Light (2010) study were that the coaches felt there was an overemphasis on training volume in the LTAD model at the expense of technique.

**Theme 4: The importance of slow swimming.** The interview findings indicated that slow swimming is vital to building good technique. This finding appears to be evident in Table 2 as 100% of the coaches surveyed (n = 11) indicated that the aerobic energy system or training zone 1 and 2 in Sweetenham and Atkinson (2003) was the most important energy system to develop during the Swim Skills (Males 9 – 12 years and Females 8 – 11 years) and Training to Train stage (Males 12 – 15 years and Females 11 – 14 years) of development.
– 14 years) of development. In addition, an expert commentary article by Greyson et al. (2010) suggests that swimming technique is best developed at slower speeds, thus pointing towards the use of aerobic swimming in order to develop good technique.

**Theme 5: Break Point Volume.** The interview findings indicated that Break Point Volume theory was one of the main guiding principles for many of the coaches’ philosophies. These findings are evident across Table 4.1 and 4.2. Table 1 highlights the average training hours, number of sessions and number of metres completed per week. The recommendations within Break Point Volume theory of roughly building towards 45 to 55,000 metres per week during maturation appear to be evident within Table 4.1. Five out of 11 coaches (45.4%) indicated that 40 – 45,000 metres per week was their average training distance prescribed during the Training to Compete stage (Males 15-18 years and Females 14 – 16 years). However for all 11 coaches this prescription ranged from 20 – 25,000 metres to 65 – 70,000 metres per week. In addition, five out of 11 coaches (45.4%) indicated that 50 – 55,000 metres per week was the average training distance prescribed during the Training to Win stage (Males 18+ years and Females 16+ years) of development. Similarly, for all 11 coaches this prescription ranged from 30 – 35,000 metres to 65 – 70,000 metres per week.

Break Point Volume suggests that youth swimmers should focus on quantity training during maturation with quality training, that is more anaerobic in nature, becoming more prominent as a swimmer reaches full maturation (Sweetenham 2006). Table 4.2 displays a similar trend towards Break Point Volume theory as highlighted by an evident shift towards developing the anaerobic energy system or training zone 3 and 4 in Sweetenham and Atkinson (2003) during the Training to Win stage (Males 18+ years and Females 16+ years) with 5 out of 11 coaches (45.4%) indicating that the anaerobic energy system was the most important energy system to develop at this stage.

There are a number of limitations to the present study. The sample only consisted of Irish swimming coaches and potentially the culture of the sport within the country may have systematically influenced the results. Therefore the results are valid within the cultural context and overall training philosophy of that particular country. The results of the questionnaire were limited due to the obvious overlap between the LTAD stages and the low number of participants. The questionnaire was pilot tested and the LTAD model was agreed by the coaches as the best available description of the various
developmental stages within a club structure for competitive swimmers in that particular country. Nevertheless, overlap clearly exists between groups.

4.6 Conclusion
Emerging trends within the swimming community and scientific literature have resulted in many questions around quality and quantity coaching philosophies. The authors felt that the coaches’ high level experiential knowledge within the sport would help to provide a context and valuable information on this topic from an applied perspective. To the best of the author’s knowledge, this was the first study to explore expert swimming coaches’ perceptions of the Quality vs Quantity debate. The explorative nature of this study has provided additional incentive to conduct further quantitative research involving HIT interventions in competitive swimmers. Controlled studies of a longer duration are needed (≥ 12 weeks) using outcome measures of physiological, biomechanical and swimming performance.
Chapter 5: Study 3 – Effects of Increased Training Volume during a 10 Day Training Camp on Competitive Performance in National Level Youth Swimmers

5.1 Abstract

Purpose: The purpose of this study was to investigate the effects of increased training volume during a 10 day training camp on competitive performance and internal training load (ITL). In addition, coach and swimmer rating of perceived exertion (RPE) for each session was compared. Methods: Ten national level swimmers (age 15.2 ± 1.3 years; height 170.5 ± 6.4 cm; body mass 61.4 ± 7.4 kg; sex 4 males and 6 females) participated in the training camp which involved a 36% increase in swimming volume. Competitive performance, assessed using the FPS (FINA points system), was recorded pre and post-camp. Internal training load was recorded using the Session-RPE method and RESTQ-52 Sport questionnaire for each session and for day 1, 5 and 10 of the camp, respectively. Coach RPE was recorded after each training session for coach-swimmer RPE comparisons. Results: Competitive performance increased by 7.1% from pre-camp to post-camp (p = 0.001, d = 1.6). Session-RPE increased between day 1 and all other days of the training camp (p < 0.05), except day 6 (p = 0.221). The injury scale of the RESTQ questionnaire increased from day 1 to day 5 (p = 0.022). Across 16 swimming sessions, there was a strong correlation between coach and swimmer RPE (rs = 0.76) however RPE was found to be higher for the swimmers than the coach (p = < 0.0005) during moderate training sessions. Conclusion: These findings suggest that a 36% increase in swimming volume during a 10 day training camp resulted in significant changes to competitive performance and ITL. However, coach and swimmer RPE should be monitored closely during future camps.
5.2 Introduction

Swimming coaches are widely acknowledged to prescribe large quantities of low intensity aerobic training with the aim of enhancing swimming performance, this is commonly referred to as high-volume training (HVT) (Maglischo 2003a, Sweetenham and Atkinson 2003). This training practice is particularly evident at youth level where training volumes of 30 to 60 km per week for 10 to 11 months of the year are common (Sein et al. 2010, Walker et al. 2012). However, uncertainties exist around the benefits of a period of increased training volume or HVT for youth swimmers as 76% of Olympic level swimming events are competed over a race distance of 200 m or less, for a typical duration of less than 2 minutes 20 seconds.

One of the earliest studies on this topic was by Costill et al. (1991) who investigated the effects of a 6 week HVT intervention involving 24 university swimmers. The swimmers were divided into a HVT and control group. The HVT group completed 3 hours of swimming per day while the control group completed 1.5 hours of swimming per day. Following the 6 week intervention, the HVT group experienced a significant reduction in 22.9 m swimming performance while the control group experienced an increase in 22.9 m swimming performance. Therefore the HVT group swam slower following the intervention however no further significant differences were found. A recently published systematic review by Nugent et al. (2016) identified 2 HVT interventions involving youth swimmers. The 4 and 5 week HVT interventions resulted in no additional improvements in physiological and swimming performance (Faude et al. 2008, Sperlich et al. 2010). Therefore a sudden increase in training volume had no additional benefits to performance. Despite this, anecdotal evidence in swimming suggests that a period of increased training volume, such as during a training camp, can improve performance. However, to date no studies have investigated the effects of increased volume, during a training camp, on competitive performance in youth swimmers.

In order to accommodate a HVT intervention during a training camp, it is necessary to monitor the training loads experienced by the swimmers. This is particularly important at youth level where overuse injury (Sein et al. 2010, Walker et al. 2012, Hibberd and Myers 2013) and overtraining syndrome (Hooper et al. 1993, Raglin et al. 2000) are common in this cohort. Training loads can be monitored both externally and internally for an athlete (Halson 2014). External training load (ETL) is defined as the work
completed by the athlete and includes monitoring tools such as recording training distance/duration, time-motion analysis and neuromuscular function testing (Halson 2014). Internal training load (ITL) is defined as the relative physiological and psychological stress imposed on the athlete and includes monitoring tools such as session-RPE, hormonal/immunological assessments and questionnaires (Halson 2014). However, many of these methods have limited use for sports scientists working with youth populations due to logistical and financial constraints. Monitoring ETL by recording training distance/duration, training intensity and frequency is an easily implemented method of quantifying ETL, particularly in a training camp environment. This would provide valuable information on the training prescriptions of youth swimmers during a training camp. In addition, ITL could be easily quantified using the session-RPE method and a questionnaire. The session-RPE method has been previously used for monitoring ITL in competitive swimmers (Wallace et al. 2009, Psycharakis 2011) and therefore would be appropriate for this population. There are numerous questionnaires available for monitoring ITL (Halson 2014). The RESTQ-Sport is a questionnaire that systematically measures the recovery-stress state of an athlete and has been previously utilised in studies during a training camp (Jürimäe et al. 2004) and across a training season (Faude et al. 2011, Di Fronso et al. 2013). However only one study has involved youth swimmers (González-Boto et al. 2008) and to the best of the authors knowledge, no studies have been conducted during a training camp period.

Monitoring ETL and ITL may be an important step to optimising an athlete’s training load, particularly during a training camp. Similarly, monitoring the relationship between coach and athlete RPE during individual sessions may help to further optimise training loads for athletic populations. This topic is receiving an increasing amount of investigation and clear discrepancies have been found between the RPE’s provided by the coach and athletes across individual training sessions (J.P. Foster et al. 2001, Wallace et al. 2009, Barroso et al. 2014, Rabelo et al. 2016). However, to the best of the author’s knowledge the coach-athlete RPE relationship has not been investigated during a training camp which may be an important consideration as training loads are commonly at their highest during these periods. Therefore any potential discrepancies between coach and athlete RPE’s should be minimalised in order to decrease risk of overtraining and injury.
The purpose of this study was to investigate the effects of increased training volume during a 10 day training camp on competitive performance. In addition, this study aimed to investigate the effects of increased training volume on ITL, specifically session-RPE and the RESTQ-Sport questionnaire, and to compare coach and swimmer’s RPE throughout the training camp. It was hypothesized that the increased training volume during the 10 day camp would lead to positive changes to competitive performance. In addition, it was hypothesized that ITL would increase during the 10 day camp in-line with periods of overloading (i.e. greater training volume). Similar to previous coach-swimmer RPE comparisons in relevant literature (Wallace et al. 2009), it was hypothesized the coaches would underestimate swimmer RPE.

5.3 Methods
5.3.1 Participants
Ten youth swimmers (4 males: age 15.5 ± 1.7 years, height 172.5 ± 3.8 cm, body mass 61 ± 2.8 kg, 100 m freestyle personal best 59.8 ± 0.8 seconds; 6 females: age 15.0 ± 1.1 years, height 169.2 ± 7.7 cm, body mass 61.7 ± 9.6, 100 m freestyle 63.1 ± 1.8 seconds) participated in this study. All of the swimmers were healthy and free from injury at the beginning of the study. The swimmers were recruited from the senior squad in a local swimming club; competing at national division 1 level; consistently performing 6 – 7 swim sessions per week (average training volume of 35 km per week) and 2 – 3 dryland sessions per week.

5.3.2 Research Design
The study was an observational design and involved recording ETL, ITL and competitive performance during a 10 day pre-competition training camp in national level youth swimmers. In addition, coach RPE for each individual session was also recorded. The training camp schedule is outlined in Table 5.1. All of the swimmers completed the entire training camp schedule.
Table 5.1 Training camp schedule

<table>
<thead>
<tr>
<th>Session</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
<th>Day 6</th>
<th>Day 7</th>
<th>Day 8</th>
<th>Day 9</th>
<th>Day 10</th>
</tr>
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<tr>
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<td>Swim</td>
<td>Swim</td>
<td>Swim</td>
<td>Swim</td>
<td>Swim</td>
<td>Swim</td>
<td>Swim</td>
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</tr>
<tr>
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<td>Swim</td>
<td>Dryland Training</td>
<td>Rest</td>
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<td>Swim</td>
<td>Dryland Training</td>
<td>Rest</td>
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<td>Rest</td>
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<td>Rest</td>
<td>Rest</td>
<td>Swim</td>
<td>Rest</td>
</tr>
</tbody>
</table>

5.3.3 Procedures

Approval to conduct this study was provided by the university ethics committee. Prior to participating, all participants (swimmers, coaches and parents/guardians) were provided with an information sheet and provided written informed consent (see Appendix 1 and 2).

*External training load.* The ETL for each participant during the camp was recorded for every training session using the coaches’ training records. The ETL was quantified by recording the total distance in meters completed at different training intensities using the training zone guidelines provided by Sweetenham and Atkinson (2003). The coach was familiar with these guidelines having consistently used them in regular training. Table 5.2 displays the daily external training load during the camp. All of the swimmers completed this ETL and no individual adjustments were needed.
Table 5.2  External training load for swimming sessions

<table>
<thead>
<tr>
<th>Session</th>
<th>Training intensity</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
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<th>Day 5</th>
<th>Day 6</th>
<th>Day 7</th>
<th>Day 8</th>
<th>Day 9</th>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>2400</td>
<td>0</td>
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</tr>
<tr>
<td>Zone 4</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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<td>0</td>
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<td>0</td>
</tr>
<tr>
<td>Zone 5</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>120</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total Distance (m)</td>
<td>3600</td>
<td>11000</td>
<td>9800</td>
<td>5130</td>
<td>10400</td>
<td>2150</td>
<td>10900</td>
<td>10400</td>
<td>9400</td>
<td>5000</td>
<td>0</td>
</tr>
</tbody>
</table>

*Zone 1: Aerobic low intensity; Zone 2: Anaerobic Threshold; Zone 3: Aerobic Overload; Zone 4: Lactate Production/Tolerance; Zone 5: Basic Speed. Data as meters (m).*
**Internal training load.** The ITL for each participant was recorded during the camp using the session-RPE method (C. Foster *et al.* 2001) and the RESTQ-52 Sport questionnaire (Kellmann and Kallus 2001). The session-RPE method has been shown to be a valid and reliable method for monitoring ITL in competitive swimmers (Wallace *et al.* 2009, Psycharakis 2011). This method involved multiplying the training session duration in minutes by the training session intensity to provide a single measure of ITL in arbitrary units (AU). The training session intensity is measured by subjectively rating the intensity of the entire session using a Rating of Perceived Exertion (RPE) according to the 10-point scale developed by Borg *et al.* (1987). In order to ensure that each subject reported a global RPE for the entire training session, the RPE was individually obtained by the lead author 45 minutes after the completion of the session (Christen *et al.* 2016). All participants were familiar with the session-RPE method having used it as part of their regular training. For the purposes of comparison, coach RPE was obtained by the lead author at the end of each training session.

The RESTQ-52 Sport was administered pre, mid and post training camp (Day 1, Day 5 and Day 10). The RESTQ-52 Sport consists of 52 items that can be grouped into 19 scales, which consists of 10 stress scales and 9 recovery scales. The 52 items are self-rated on a 7-point Likert scale and indicate how often the subject has participated in various activities during the past three days/night. In addition, a total stress score can be calculated by summing the scales 1 – 7 and 13 – 15 and a total recovery score can be calculated by summing the scales 8 – 12 and 16 – 19. The internal consistencies and reliability of the RESTQ-Sport have previously been reported with Cronbach’s alpha (0.67 – 0.88) and the test-retest reliability ($r = 0.51 – 0.81$) (Kellmann and Kallus 2001). All participants were familiar with the RESTQ-52 Sport having used it as part of regular monitoring procedures. The questionnaire was completed individually in a quiet location and at the same time of day.

**Competitive performance.** The swimmers’ competitive performance was measured both pre and post-camp at two national level swimming competitions. The competitions were held in the same 50 m pool (pool temperature: 26 degrees; pool depth: 2.5 m). The pre-camp measures were recorded 2 days prior to the training camp and the post-camp measures were recorded 2 weeks after the training camp. The swimmers’ best competitive stroke event across the two competitions was evaluated using the FINA Point Scoring System (FPS) which enables the grading of each swimmer’s performance
independent of the swimmer’s technique or distance swam (FINA points table 2011). The FPS assigns point values to swimming performance, with more points for world class performances and less points for slower performances. Test-retest reliability of competitive performance for this sample, as assessed using the FPS, was high (ICC = 0.97, CV = 2.7%). Eight swimmers competed in 100 and 200 m events (two medley, three breaststroke, four freestyle) and one swimmer in the 400 m freestyle event. One swimmer did not complete the post-camp competition and therefore the data was removed from analysis.

5.3.4 Statistical Analysis
All data was analysed with SPSS v.21.0 (SPSS Inc, Chicago, Illinois, USA). The level of significance was set at p < 0.05. The data was checked for normality using visual inspection and the Shapiro-Wilk test. Parametric statistics were used on normally distributed data and non-parametric statistics were used on non-normally distributed data. Parametric data are expressed as mean and standard deviations (Mean ± SD) and non-parametric data are expressed as median (Mdn) and interquartile ranges (IQR). Repeated measures parametric data was checked for sphericity using Mauchly’s test and if violated the Greenhouse-Geisser correction was used.

A paired samples t-test was used to determine whether there were differences between the participant’s pre and post-camp competitive performance. A one-way repeated measures analysis of variance (ANOVA) with Bonferroni adjustment was used to determine whether there were differences in session-RPE over the course of the 10 day training camp. A one-way repeated measures ANOVA was used to determine whether there were differences in total recovery and stress scores over the course of the 10 day training camp. A Friedman test was used to determine if there were differences in the individual scales of the RESTQ-Sport questionnaire over the course of the 10 day training camp. When a significant effect was found, pairwise comparisons were performed with a Bonferroni correction for multiple comparisons.

A Spearman’s rank-order correlation was used to assess the relationship between coach and swimmer RPE during the 16 swimming sessions of the training camp. Training-session intensities were divided into easy (RPE < 3), moderate (RPE 3 – 5) and hard (RPE > 5) based on the coaches’ perception. Three separate Mann-Whitney U tests were performed to determine if there were differences in RPE scores between the coach
and swimmers across easy, moderate and hard training sessions during the camp. Levene’s test was used to meet the assumption of equal distributions between the RPE scores of the coach and swimmers. If the assumption of equal distributions was violated, mean rank values were used to describe the data.

Where possible, effect sizes were calculated using partial eta squared (\(\eta_p^2\)) for analysis of variances or Cohen’s \(d_c\) for paired comparisons. Partial eta squared (\(\eta_p^2\)) was interpreted as follows: small (0.01), medium (0.06) and large (0.15) (Cohen 1988). Cohen’s \(d_c\) was interpreted as follows: small (< 0.50), moderate (0.50 – 0.80) and large > 0.80 (Cohen 1988).

5.4 Results

Participants completed all of the testing points throughout the study. When compared with a pre-camp 10 day training period, swimming volume increased by 36% (from 50 to 77.8 km respectively) during the training camp. There was no increase to dryland training volume. The training camp consisted of 19 sessions (16 swimming and 3 gym sessions) with the swimmers completing 7.8 ± 3.4 km per day during the 10 day training camp (see Table 5.2).

According to FPS competition points, there was a 7.1% increase in pre-camp to post-camp competitive performance (\(p = 0.001, d_c = 1.6\)), see Figure 5.1. Male swimmers (n = 3) experienced an increase in competitive performance from 448 ± 43 FPS points during the pre-camp competition to 484 ± 41 FPS points during the post-camp competition. Female swimmers (n = 6) experienced an increase in competitive performance from 517 ± 64 FPS points during the pre-camp competition to 551 ± 75 FPS points during the post-camp competition.
Figure 5.1 – FPS points for pre-camp to post-camp competitive performance (n = 9). Dotted lines are individual data points. Bold line is the mean. aDifference between pre-camp to post-camp (p = 0.001, d_z = 1.6). FPS points: FINA Point Scoring System which enables the grading of each swimmer’s performance independent of the swimmer’s technique or distance swam.

The training camp elicited significant differences in session-RPE over time (p < 0.0005, \( \eta^2_p = 0.865 \)). Post hoc analysis with Bonferroni adjustment revealed significant differences between day 1 (baseline) and all other days of the training camp (p < 0.0005) except day 6 (p = 0.221, see Figure 5.2). When the total recovery and total stress score for day 1, day 5 and day 10 were analysed, the training camp did not elicit significant differences in the total recovery score over time (p = 0.876, \( \eta^2_p = 0.015 \)) or the total stress score over time (p = 0.055, \( \eta^2_p = 0.028 \), see Figure 5.3). However, the training camp elicited significant differences in the injury scale of the RESTQ-Sport questionnaire over time (p = 0.012). Post hoc analysis revealed a significant increase in the injury scale from day 1 (Mdn = 1.63, IQR = 1.13 – 2.25) to day 5 (Mdn = 2.50, IQR = 1.44 – 3.50, p = 0.022), but not day 5 to day 10 (p = 0.281) or day 1 to day 10 (p = 0.943). In addition, the training camp elicited significant differences in the general well-being scale of the questionnaire over time (p = 0.044). However, further post hoc analysis found the only difference that was borderline significance was day 1 to 10 (p = 0.076).
Figure 5.2 – Session-RPE for day 1 – 10 of the training camp. *Difference from day 1 (p < 0.0005). †Difference from day 1 to 5 (p < 0.0005). ‡Difference from day 5 to day 10 (p = 0.001). AU: arbitrary units. Data as mean ± SD.

Figure 5.3 – Total recovery score (sum of scales 8 – 12 and 16 – 19) and total stress score (sum of scales 1 – 7 and 13 – 15) for day 1, 5 and 10 of the training camp. No significant differences at any point (p > 0.05 for all). Data as mean ± SD.

There was a strong positive correlation between the coach and the swimmers’ RPE across the 16 swimming sessions of the 10 day training camp, $r_s = 0.76$, p < 0.0005, see Figure 5.4. Further analysis was performed by dividing the 16 swimming sessions into easy (RPE < 3), moderate (RPE 3 – 5) and hard (RPE > 5) based on the coach’s perception, see Figure 5.5. During easy sessions, RPE scores for the coach (mean rank = 8) and the swimmers (mean rank = 13) were not significantly different (p = 0.063).
During moderate sessions, RPE scores for the swimmers (mean rank = 124.45) were significantly higher than for the coach (mean rank = 96.55, \( p < 0.0005 \)). During hard sessions, RPE scores for the coach (mean rank = 44.75) and the swimmers (mean rank = 36.25) were not significantly different (\( p = 0.092 \)).

![Figure 5.4](image1)

**Figure 5.4** – Scatterplot and Spearman’s rank-order correlation between coach and swimmers RPE for 16 swim sessions during the 10 day training camp.

![Figure 5.5](image2)

**Figure 5.5** – RPE scores for coach and swimmers during easy, moderate and hard training sessions during the 10 day camp. *Difference between coach and swimmer RPE during moderate sessions. Data as median and IQR.*

### 5.5 Discussion

The purpose of this study was to investigate the effects of increased training volume during a 10 day training camp on competitive performance. In addition, this study aimed to investigate the effects of increased training volume on ITL and to compare
coach and swimmers’ RPE throughout the training camp. The main finding of this study was that a 36% increase in swimming volume resulted in significant changes to competitive performance. In addition, the increased training volume resulted in significant changes to ITL, specifically session-RPE and the RESTQ-Sport questionnaire, and coaches were found to underestimate swimmers’ RPE for moderate training sessions (RPE 3 – 5) during the camp.

Mean competitive performance across primarily 100 and 200 m events was found to increase by 7.1% from pre to post-camp. This is an interesting finding and appears to suggest that the 36% increase in training volume during the camp may have improved competitive performance across events that are predominantly less than 3 minutes duration. This is in contrast to previous studies which found that a 4 to 6 week period of increased training volume or HVT resulted in no additional improvements in physiological and swimming performance (Costill et al. 1991, Faude et al. 2008, Sperlich et al. 2010). The findings of our study appear to indicate that the youth swimmers benefited from the 36% increase in training volume during the camp. This increase in training volume may have been optimal for this cohort as competitive performance increased while the swimmers’ recovery-stress state was largely unchanged. However, a limitation to this finding was that the post-camp competition was conducted 2 weeks after the training camp and due to logistical constraints no detailed data was recorded during this period. Despite this, the training volume of the group remained consistent during this period with average weekly training volumes of 35 km per week. Therefore, a taper was not implemented prior to the post-camp competition which was similar to the pre-camp competition.

Analysis of the swimmers’ recovery-stress state revealed that only 2 out of 19 scales of the RESTQ-Sport questionnaire significantly changed during the training camp despite a 36% increase in training volume. The injury scale of the questionnaire significantly increased from day 1 to 5 and the general well-being scale significantly changed over time however the only difference that was borderline significance was between days 1 to 10. This finding may indicate that the study was underpowered and if more data was collected, there may have been a significant change to the general well-being scale between days 1 to 10. Additionally there were no significant differences to total recovery scores and total stress scores during the training camp. Previous studies have found the scales of the RESTQ-Sport questionnaire to be sensitive to periods of
overload during a training camp (Jürimäe et al. 2004) and across a training season (Faude et al. 2011, Di Fronso et al. 2013). However only one study has involved youth swimmers (González-Boto et al. 2008) and to the best of the authors knowledge, no studies have been conducted during a training camp period. This finding appears to indicate that the youth swimmers in this study coped with the increased training volume during the camp.

A strong positive correlation ($r_s = 0.76$) was found between coach and swimmers’ RPE for the 16 swimming sessions of the training camp. Therefore, the RPE scores of the coach and swimmers were strongly associated, which supports the notion that this was a well-structured and balanced training camp that resulted in increased post-camp competitive performance. A number of studies have investigated the coach-athlete RPE relationship (J.P. Foster et al. 2001, Barroso et al. 2014, Rabelo et al. 2016). J.P. Foster et al. (2001) investigated the relationship between coach and athlete RPE during a 5 week training period in competitive runners and found a strong positive correlation ($r = 0.75$). Barroso et al. (2014) investigated the relationship between coach and swimmer RPE during nine training sessions across different age cohorts. The study concluded that the correlation between coach and swimmer RPE increased with increasing age and competitive swimming experience. The cohort of 15 – 16 year old swimmers had the strongest correlation with coach RPE ($r = 0.74$) which is similar to the age range and correlation found in our study. To the best of the author’s knowledge our study is the first to investigate this relationship during a training camp. Monitoring the coach-athlete RPE relationship during a training camp may be crucial as training loads are commonly at their highest during these periods and therefore risk of overtraining and injury are greatest, particularly at youth level.

Further analysis revealed that the swimmers’ RPE was significantly higher than coach’s RPE for moderate training sessions (RPE 3 – 5) during the camp. Therefore the coach underestimated swimmers’ RPE, which was hypothesized, and is similar to previous coach-swimmer RPE comparisons in the literature (Wallace et al. 2009, Barroso et al. 2014). Wallace et al. (2009) compared coach-swimmer RPE during 20 training sessions for senior swimmers and found that swimmers’ RPE was significantly higher than coach RPE during low-intensity training sessions (RPE < 3) however swimmer RPE was significantly lower than coach RPE during moderate and high-intensity sessions (RPE 3 – 5 and RPE > 5, respectively). Barroso et al. (2014) reported similar findings in
youth swimmers during nine training sessions with coaches underestimating the swimmers’ RPE during low-intensity sessions and overestimating swimmers’ RPE during high-intensity sessions. The novelty of our findings were that the coach-swimmer RPE was compared during 16 sessions of a training camp for youth swimmers which has not previously been conducted.

5.6 Conclusion

Training camps are traditionally periods that involve a distinct overloading phase whereby training volume, intensity or frequency are increased. This may increase the risk of overtraining and injury if not conducted appropriately, particularly with youth athletes. The findings of this study suggest that a 36% increase in swimming volume during a 10 day training camp resulted in significant changes to subsequent competitive performance in youth swimmers. In this group of youth swimmers, the increase in swimming volume during the camp may have been optimal as suggested by the limited changes to the swimmers’ recovery-stress state while competitive performance improved. However, coach and swimmer RPE should be monitored closely during training sessions to ensure there are no significant differences, particularly during training camps. Future studies should investigate if greater increases to swimming volume during a training camp result in changes to a swimmer’s recovery-stress state and subsequent competitive performance.
Chapter 6: Study 4 – The Effects of Low-Volume, High-Intensity Training on Performance Parameters in Competitive Youth Swimmers

6.1 Abstract

Purpose: To assess the effects of a 7 week low-volume, high-intensity training (HIT) intervention on performance parameters in national level youth swimmers. Methods: Sixteen swimmers (age 15.8 ± 1.0 years, age at peak height velocity 12.9 ± 0.6 years, 100 m freestyle personal best time 61.4 ± 4.1 s) were randomly assigned to a HIT group or low-intensity, high-volume training (HVT) group which acted as a control. The HIT group reduced their weekly training volume of zone 1 (low-intensity) training by 50% but increased zone 3 (high-intensity) training by 200%. The HVT group performed training as normal. Pre to post-test measures of physiological performance (velocity at blood lactate concentrations of 2.5 mM and 4 mM [velocity\textsubscript{2.5mM} and velocity\textsubscript{4mM}] and peak blood lactate), biomechanical performance (stroke rate [SR], stroke length [SL] and stroke index [SI] over a 50 and 400 m freestyle) and swimming performance (50 m, 200 m and 400 m freestyle) were assessed. Results: There were no significant three-way interactions between time, group and sex for performance parameters (p > 0.05). There was a significant two-way interaction between time and group for velocity\textsubscript{4mM} (p = 0.020, \eta^2 = 0.40), SL\textsubscript{50} (p = 0.034, \eta^2 = 0.37) and SI\textsubscript{50} (p = 0.029, \eta^2 = 0.39). Velocity\textsubscript{4mM} decreased in the HIT group but increased in the HVT group while SL\textsubscript{50} and SI\textsubscript{50} decreased in the HVT group. Conclusions: A 7 week HIT intervention was neither beneficial nor detrimental to performance parameters however the HIT group completed 6 hours (17.0 km) of swimming per week compared to 12 hours (33.4 km) per week for the HVT group.
6.2 Introduction

Swimming is a cyclical sport with unique physiological and biomechanical demands due to the large variety of racing distances spread across multiple swimming stroke techniques. There are thirty-two pool based events at the Olympic Games which range in distance from 50 to 1,500 m. The Gold medal winning times at the Rio 2016 Olympics ranged from 21.40 seconds for the 50 m event to approximately 14 minutes 34.57 seconds for the 1,500 m event. However twenty-six out of the thirty-four (76%) Olympic swimming events are competed over a race distance of 200 m or less, for a typical duration of less than 2 minutes 20 seconds. Despite the short duration of the majority of swimming events, the traditional training practices of competitive swimmers typically involve high training volumes (i.e. total training distance or duration) which are in many cases well in excess of other cyclical sports such as running, rowing and cycling (Seiler and Tønnessen 2009). This is particularly evident at youth level where training volumes may range from 11 to 20 hours per week spread across 6 to 11 training sessions (Sein et al. 2010, Nugent et al. 2017).

Swimming performance is determined by a number of different physiological and biomechanical parameters (Jürimäe et al. 2007, Psycharakis et al. 2008, Barbosa et al. 2010b, Mezzaroba and Machado 2014). Biomechanical parameters such as stroke rate (number of swimming stroke cycles performed per minute), stroke length (distance the swimmer travels per stroke cycle) and stroke index (stroke length multiplied by swimming velocity; an indication of stroke efficiency) are among the best determinants of swimming performance (Jürimäe et al. 2007, Barbosa et al. 2010b, Mezzaroba and Machado 2014). This is perhaps one of the incentives for undertaking high training volumes as swimming coaches continually suggest that large amounts of practice are required to develop efficient stroke mechanics (Greyson et al. 2010, Nugent et al. 2017). In recent years, a topic which is increasingly being investigated is the use of HIT programmes versus HVT programmes to improve swimming performance (Faude et al. 2008, Nugent et al. 2016, Nugent et al. 2017). A number of high profile international swimmers have had success using HIT programmes which are in contrast to more traditional HVT programmes and this has led to debate among the swimming community (Stott 2014, Beliaev 2015). Anecdotal evidence suggests that many of the best swimming coaches and athletes of all time are advocates of HVT, hence the controversy.
Optimising training programme design is a widely researched topic in cyclical sports (Seiler 2010, Enoksen et al. 2011, Stoggl and Sperlich 2014, Stoggl and Sperlich 2015). Training programs for cyclical sports are comprised of low-intensity training (zone 1, < 2 mM blood lactate), moderate-intensity training (zone 2, 2 – 4 mM blood lactate) and high-intensity training (zone 3, > 4 mM blood lactate) (Seiler 2010). A HIT training programme is defined as a lower volume programme which focuses on performing intervals of high-intensity training to improve performance (Stoggl and Sperlich 2015). A HVT training programme is defined as a higher volume programme which focuses on performing prolonged low-intensity training to improve performance (Stoggl and Sperlich 2015). A recently published systematic review by Nugent et al. (2016) investigated the effects of a HIT intervention on performance in competitive swimmers. Seven studies met the inclusion criteria, ranging in duration from 4 weeks to 4 years and were conducted on youth, university, masters and elite swimmers. Six out of the 7 studies found that HIT resulted in improvements to performance measures such as maximal rate of oxygen consumption and swim velocity at fixed blood lactate values. Four of the 7 studies found that HIT resulted in improvements to performance in events from 50 to 2000 m, whilst none of the seven studies resulted in a reduction in performance. The review concluded that the applications of HIT may be limited as a number of the controlled studies were only 4 to 5 weeks duration therefore more research is required.

To the best of the author’s knowledge, the effects of HIT on biomechanical parameters in competitive swimmers have not been investigated. Swimming coaches have suggested that HIT programmes may be detrimental to technical development as swimming technique is best practiced at low-intensities (Greyson et al. 2010, Nugent et al. 2017). This topic warrants further investigation. In addition, none of the previous HIT studies have accurately quantified the training completed by the HIT and HVT groups. This is important during swimming interventions as different stroke techniques (e.g. butterfly) and technical exercises (e.g. kicking and arm pulling drills) can result in varied metabolic responses (Barbosa et al. 2006, Rodríguez 2016). The current study aimed to address this methodological flaw by assessing physiological, biomechanical and perceptual responses to individual HIT and HVT sessions. The main purpose of this study was to assess the effects of a 7 week HIT intervention on performance parameters in national level youth swimmers. Due to the competition schedule it was not possible to conduct an intervention of longer duration.
6.3 Methods

6.3.1 Participants

Sixteen swimmers from the senior team of a local swimming club volunteered to partake in this study (Table 6.1). The swimmers were all competing at top tier national level competition in 50 – 400 m events, consistently completed 6 – 7 swim sessions and 2 – 3 gym sessions per week, and had a mean swimming volume of 35 km (12 hours) per week. All of the swimmers were healthy and free from injury at the beginning of the study.

Table 6.1 Anthropometric and performance characteristics for the HIT and HVT group

<table>
<thead>
<tr>
<th>Variables</th>
<th>HIT (n = 8)</th>
<th>HVT (n = 8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (n, male/female)</td>
<td>3/5</td>
<td>3/5</td>
</tr>
<tr>
<td>Age (years)</td>
<td>16.0 ± 1.1</td>
<td>15.6 ± 0.9</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>66.3 ± 10.6</td>
<td>65.3 ± 12.5</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>174.9 ± 9.3</td>
<td>172.3 ± 10.0</td>
</tr>
<tr>
<td>Age at peak height velocity (years)</td>
<td>12.9 ± 0.5</td>
<td>13.0 ± 0.6</td>
</tr>
<tr>
<td>100-m freestyle personal best time (s)</td>
<td>61.1 ± 3.8</td>
<td>61.6 ± 4.6</td>
</tr>
</tbody>
</table>

6.3.2 Research Design

The study incorporated a randomised controlled design. The study was approved by the University of Limerick Ethics Committee and procedures were in accordance with the Declaration of Helsinki. All participants and their parents/guardians signed an informed consent form prior to participation (see Appendix 1 and 2). The swimmers were matched for sex (male or female) and randomly allocated, by flipping a coin, into either a HIT group or control (HVT) group (Table 6.1). The study was conducted during the third general preparation phase (week 36 – 43) of a 48 week season. Prior to the study, the swimmers trained as normal which was a HVT programme based on the results of pilot testing that was conducted during the previous and current season, indicating that ~95% of the training volume was in zone 1 with ~5% performed in zone 2 – 3 (Stoggl and Sperlich 2014).

In order to investigate the effects of a HIT intervention, the swimming coach (21 years’ experience, level 3 Swim Ireland coach, multiple international medallists) of the team was asked to reduce mean weekly zone 1 (see 2.6 Establishing training zones) training volume by 50% and to increase mean weekly zone 3 (see 2.6 Establishing training
zones) training volume by 200%, based on previous studies (Faude et al. 2008, Kilen et al. 2014, Pugliese et al. 2015). The control group trained as normal using a HVT programme. The lead author was present during every training session. In order to ensure that the training volume distributions for both groups were valid, the swimming coach’s training prescriptions were analysed on a daily basis (Table 6.2). In addition, physiological, biomechanical and perceptual data was collected during 10 random training sessions for both groups (Table 6.3).
Table 6.2 The swimming coaches’ distribution of total training volume during the 7 week intervention

<table>
<thead>
<tr>
<th>Training zone</th>
<th>Descriptors</th>
<th>Example training sets</th>
<th>HIT (km)</th>
<th>% of total</th>
<th>HVT (km)</th>
<th>% of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Low-intensity training: &lt;2 mM blood lactate, &lt;80% HRmax, session-RPE ≤4</td>
<td>3 × 300 m warm up (changing each 50 m – swim, drill, swim), rest 20 s</td>
<td>97.4</td>
<td>81.7</td>
<td>223.9</td>
<td>95.8</td>
</tr>
<tr>
<td>2</td>
<td>Moderate-intensity training: 2 – 4 mM blood lactate, 80 – 87% HRmax, session-RPE 5 – 6</td>
<td>10 × 100 m threshold kick, rest 20 s</td>
<td>2.2</td>
<td>1.9</td>
<td>2.9</td>
<td>1.2</td>
</tr>
<tr>
<td>3</td>
<td>High-intensity training: &gt;4 mM blood lactate, &gt;87% HRmax, session-RPE ≥7</td>
<td>20 × 50 m at individualised 400-m race pace, rest 20 s</td>
<td>19.6</td>
<td>16.4</td>
<td>6.9</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Descriptors based on the recommendations of Seiler (2010)
The HIT group swam for a mean of 1 hour (2.8 km) per session and the HVT group swam as normal for 2 hours (5.6 km) per session. Each session was divided into a warm up, main session and cool down. The warm up consisted of zone 1 training for both groups which was performed using a variety of technical drills, kicking and pulling exercises. During the main session, the HIT group performed zone 3 training as 25 – 100 m intervals at an individualised race pace velocity for 50 – 400 m events across all swimming strokes. This was performed three days per week and zone 1 training was performed on alternative days. The HVT group trained as normal which primarily involved zone 1 training across all swimming strokes. The cool down consisted of zone 1 training for both groups. Training volume and zone distribution during the 7 week intervention for the HIT and HVT group are summarised in Figure 6.1.

Figure 6.1 – Training volume and zone distribution during the 7 week intervention for the HIT and HVT group.
6.3.3 Procedures

Performance tests were conducted over a two day period in the week prior to and after the intervention. All subjects were familiar with the performance tests having performed them previously. The testing was conducted during normal training hours in a 50 m indoor pool (depth: 2.4 m and temperature: 27 – 28°C). Dietary intake, prior exercise up to 48 hours and warm up procedures were standardized during testing.

Physiological performance. On day 1 of testing, physiological performance was assessed using the 7 × 200 m incremental test outlined by Pyne et al. (2001). The test involves performing seven 200 m freestyle swims on a 5 minute interval at graded intensities from easy to maximal. The seventh and final swim was a maximal effort and served as a measure of 200 m swimming performance. Each 200 m swim was performed from a “push start” and maintaining an “even pace” was emphasised to swimmers. The swimmers were highly familiar with maintaining an “even pace” during training however an auditory signal was provided at the end of each 100 m to ensure swimmers were pacing correctly. The time for each 200 m interval was recorded by an experienced swim coach (> 7 years coaching experience) using a Finis chronometer (Model 3X-300M, USA) and to the nearest 0.01 second. Immediately after completion of each 200 m interval, heart rate (HR) was measured using the Cardio Swim system (Freelap, Switzerland) which measured beat-by-beat HR during each swimming interval. A rating of perceived exertion (RPE) was assessed using the Borg 6 – 20 Scale (Borg 1982) and a blood lactate sample was taken from the earlobe using a Lactate Pro 2 analyser (ARKRAY Europe, Netherlands) at the end of each interval. Additionally, in order to determine a peak blood lactate (BL\text{peak}) value, lactate was collected immediately after completion of the seventh 200 m, at 2 and 5 minutes post 200 m swim. The lactate-velocity curve was plotted using Lactate-e software (Newell et al. 2007) for determination of velocity at fixed blood lactate markers of 2.5 mM and 4 mM which are commonly utilised markers of the lactate and anaerobic threshold, respectively (Newell et al. 2007). The reliability values for velocity at fixed blood lactate markers (ICC = 0.85 – 0.96, CV = 0.7 – 1.1%) and BL\text{peak} (ICC = 0.81, CV = 11.3%) have been shown to be acceptable (Turner et al. 2008).

Biomechanical performance. On day 2 of testing, biomechanical performance was assessed using the methods outlined by Smith et al. (2002) to calculate swimming velocity (SV), stroke rate (SR), stroke length (SL) and stroke index (SI) over a 50 and
400 m freestyle time trial. A 20 m mid-pool section was used to measure these parameters in order to exclude the influence of the start (0 – 15 m) and the turn (5 – 7.5 m from the wall). A video camera (JVC Everio, Model GZ-MG130EK, USA) sampling at 50 Hz was placed in an elevated position at the 25 m mark of the 50 m pool. The recording was later analysed using Sportscode 11.0 software (Hudl, Agile Sports Technologies) in order to calculate SV, SR, SL and SI over the 20-m mid-pool section. Swimming velocity (SV) was calculated to the nearest 0.01 m/s using the formula: 

\[
SV (\text{m/s}) = \frac{20}{\text{time (s)}}
\]

Stroke rate (SR) was calculated by timing three stroke cycles using a Finis chronometer (Model 3X-300M, USA). SR was measured three times over the 20 m mid-pool section and the median value was used for analysis. SL was calculated as follows: 

\[
SL (\text{m/stroke}) = \frac{SV (\text{m/s})}{SR (\text{strokes/s})}
\]

SI was calculated as follows: 

\[
SI = SV (\text{m/s}) \times SL (\text{m/stroke})
\]

Swimming velocity (SV) was calculated to the nearest 0.01 m/s using the formula: 

\[
SV (\text{m/s}) = \frac{20}{\text{20 m time (s)}}
\]

Stroke rate (SR) was calculated by timing three stroke cycles using a Finis chronometer (Model 3X-300M, USA). SR was measured three times over the 20 m mid-pool section and the median value was used for analysis. SL was calculated as follows: 

\[
SL (\text{m/stroke}) = \frac{SV (\text{m/s})}{SR (\text{strokes/s})}
\]

SI was calculated as follows: 

\[
SI = SV (\text{m/s}) \times SL (\text{m/stroke})
\]

The mean value of SR, SL and SI over every 50 m of the 400 m time trial was used for analysis. The reliability of SR, SL and SI has been shown to be moderate to excellent (ICC = 0.78 – 0.98, CV = 2.4 – 4.9%) (Bassan et al. 2016).

Swimming performance. On day 2 of testing, swimming performance was assessed using a 50 and 400 m freestyle time trial from starting blocks. The time trials were performed as a mock competition by matching swimmers, based on previous performance times, thus ensuring a maximal effort. There was a 20 minute active recovery interval between time trials. The times were recorded by an experienced swim coach (> 7 years’ experience) using a Finis chronometer (Model 3X-300M, USA) and to the nearest 0.01 second.

6.3.4 Statistical Analysis

All data was analysed with SPSS 21.0 software (SPSS Inc, Chicago, Illinois, USA). The level of significance was set at p < 0.05. The data was checked for normality using visual inspection and the Shapiro-Wilk test. Independent-samples t-tests were conducted to determine if there were differences between the groups demographics at baseline, compliance rate, and individual responses (physiological, biomechanical and perceptual) to the HIT and HVT group training sessions. A three-way analysis of variance (ANOVA) with repeated measures was conducted to determine the effects of time, group and sex on performance parameters. The within-subject factor was time (pre-test vs post-test). The two between-subject factors were group (HIT vs HVT) and sex (male vs female). The Levene’s test was used to check for homogeneity of
variances. Effect sizes are described using partial eta squared ($\eta_p^2$) and were interpreted as follows: small ($\geq 0.01$), medium ($\geq 0.06$) and large ($\geq 0.15$) (Cohen 1988).

6.4 Results

One swimmer in the HIT group did not complete post-testing due to an injury and therefore their data was excluded from the final analysis. There were no significant differences between the group’s demographics at baseline ($p > 0.05$). There was no significant difference in the compliance rate for the HIT group (87.8 ± 6.2%) and HVT group (93.2 ± 5.6%, $p = 0.10$) during the study. The mean training volume for the HIT group was 17.0 ± 2.2 km per week and 33.4 ± 3.2 km per week for the HVT group. The total training volume across the 7 week intervention was 119.2 km for the HIT group and 233.7 km for the HVT group. There were significant differences in physiological, biomechanical and perceptual responses to the HIT and HVT group training sessions ($p < 0.001$ for all, Table 6.3).
<table>
<thead>
<tr>
<th>Variables</th>
<th>HIT (n = 7)</th>
<th>HVT (n = 8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean HR (beats/min)</td>
<td>181 ± 7</td>
<td>152 ± 9*</td>
</tr>
<tr>
<td>Peak HR (beats/min)</td>
<td>192 ± 8</td>
<td>180 ± 11*</td>
</tr>
<tr>
<td>Blood lactate (mM)</td>
<td>6.7 ± 2.7</td>
<td>1.9 ± 0.8*</td>
</tr>
<tr>
<td>Mean velocity (m/s)</td>
<td>1.43 ± 0.15</td>
<td>1.10 ± 0.09*</td>
</tr>
<tr>
<td>Peak velocity (m/s)</td>
<td>1.56 ± 0.18</td>
<td>1.37 ± 0.10*</td>
</tr>
<tr>
<td>Mean SR (strokes/min)</td>
<td>39 ± 6</td>
<td>26 ± 4*</td>
</tr>
<tr>
<td>Mean RPE (6 – 20)</td>
<td>17.4 ± 1.9</td>
<td>11.9 ± 1.4*</td>
</tr>
<tr>
<td>Session-RPE (1 – 10)</td>
<td>7.8 ± 1.4</td>
<td>3.7 ± 1.2*</td>
</tr>
</tbody>
</table>

All values are calculated as the mean ± SD of 10 random training sessions for the HIT group (45 individual data sets) and HVT group (43 individual data sets).

HR and velocity values are the mean and peak of the main session (i.e. excluding warm up and cool downs).

Blood lactate values were obtained at least two times during the second half of each main session.

Stroke rate and RPE values were obtained three times over the main session and a mean was calculated.

Session-RPE was recorded at least 30 minutes after each session.

*Independent samples t-test. Both group variables were significantly different from each other (p < 0.001).

Descriptive statistics of physiological performance, biomechanical performance, swimming performance parameters for the HIT and HVT group are provided in Table 6.4. There were no significant three-way interactions between time, group and sex for physiological performance (velocity\textsubscript{2.5mM}, velocity\textsubscript{4mM}, BL\textsubscript{Apeak}), biomechanical performance (SR\textsubscript{50}, SL\textsubscript{50}, SI\textsubscript{50}, SR\textsubscript{400}, SL\textsubscript{400}, SI\textsubscript{400}), swimming performance (50\textsubscript{freestyle}, 200\textsubscript{freestyle} and 400\textsubscript{freestyle}) and recovery-stress state (p > 0.05 for all; Table 6.4). There was a significant two-way interaction between time and group for velocity\textsubscript{4mM} (F\textsubscript{1, 11} = 7.34, p = 0.02, \eta\textsuperscript{2} = 0.40, Figure 6.2), SL\textsubscript{50} (F\textsubscript{1, 10} = 5.99, p = 0.03, \eta\textsuperscript{2} = 0.37, Figure 6.2) and SI\textsubscript{50} (F\textsubscript{1, 10} = 6.49, p = 0.03, \eta\textsuperscript{2} = 0.39, Figure 6.2). All other two-way interactions were not significant (p > 0.05). There was a significant main effect of time for 50\textsubscript{freestyle} (F\textsubscript{1, 11} = 5.16, p = 0.04, \eta\textsuperscript{2} = 0.32, Table 6.4) while the main effect of time for 200\textsubscript{freestyle} was borderline significant (F\textsubscript{1, 11} = 4.31, p = 0.06, \eta\textsuperscript{2} = 0.28, Table 6.4).
Table 6.4 Descriptive statistics of the physiological parameters, biomechanical parameters and swimming performance parameters for the HIT and HVT group (n = 15)

<table>
<thead>
<tr>
<th>Variables</th>
<th>HIT (n = 7)</th>
<th>HVT (n = 8)</th>
<th>ANOVA p values and Effect Sizes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
</tr>
<tr>
<td>Velocity_{2.5mm} (m/s)</td>
<td>1.24 ± 0.09</td>
<td>1.24 ± 0.05</td>
<td>1.25 ± 0.07</td>
</tr>
<tr>
<td>Velocity_{4mm} (m/s)</td>
<td>1.32 ± 0.07</td>
<td>1.30 ± 0.07</td>
<td>1.31 ± 0.07</td>
</tr>
<tr>
<td>BL_{peak} (mM)</td>
<td>9.3 ± 4.4</td>
<td>9.7 ± 3.0</td>
<td>9.7 ± 2.6</td>
</tr>
<tr>
<td>SR_{50} (strokes/min)</td>
<td>49.9 ± 8.0</td>
<td>49.1 ± 8.1</td>
<td>49.1 ± 4.3</td>
</tr>
<tr>
<td>SL_{50} (m/stroke)</td>
<td>1.98 ± 0.22</td>
<td>1.98 ± 0.25</td>
<td>2.03 ± 0.25</td>
</tr>
<tr>
<td>SI_{50}</td>
<td>3.22 ± 0.45</td>
<td>3.17 ± 0.49</td>
<td>3.34 ± 0.59</td>
</tr>
<tr>
<td>SR_{400} (strokes/min)</td>
<td>34.7 ± 2.6</td>
<td>34.5 ± 2.6</td>
<td>34.7 ± 3.2</td>
</tr>
<tr>
<td>SL_{400} (m/stroke)</td>
<td>2.18 ± 0.15</td>
<td>2.20 ± 0.16</td>
<td>2.22 ± 0.31</td>
</tr>
<tr>
<td>SI_{400}</td>
<td>2.72 ± 0.30</td>
<td>2.77 ± 0.33</td>
<td>2.90 ± 0.56</td>
</tr>
<tr>
<td>50_{freestyle} (m/s)</td>
<td>1.72 ± 0.16</td>
<td>1.70 ± 0.15</td>
<td>1.71 ± 0.12</td>
</tr>
<tr>
<td>200_{freestyle} (m/s)</td>
<td>1.36 ± 0.08</td>
<td>1.37 ± 0.09</td>
<td>1.37 ± 0.07</td>
</tr>
<tr>
<td>400_{freestyle} (m/s)</td>
<td>1.31 ± 0.09</td>
<td>1.31 ± 0.09</td>
<td>1.33 ± 0.08</td>
</tr>
</tbody>
</table>

Values are mean ± SD
BL_{A}: blood lactate, SR: stroke rate, SL: stroke length, SI: stroke index
Figure 6.2 – A significant two-way interaction between time and group for velocity_{4mM} (p = 0.02, \eta_p^2 = 0.40), SL_{50} (p = 0.03, \eta_p^2 = 0.37) and SI_{50} (p = 0.03, \eta_p^2 = 0.39).

Abbreviations: * indicates a significant interaction (p < .05); Velocity_{4mM} indicates swim velocity (m/s) at a fixed blood lactate of 4 mM; SL_{50} indicates stroke length (m/stroke) over the 50 m freestyle time trial; SI_{50} indicates stroke index over the 50 m freestyle time trial.
6.5 Discussion

The purpose of this study was to assess the effects of a 7 week HIT intervention on performance parameters in national level youth swimmers. The main finding of this study was that a 7 week HIT intervention resulted in a decrease to velocity$\text{4mM}$ in the HIT group and an increase in the HVT group (Figure 6.2) while both SL$\text{50}$ and SI$\text{50}$ decreased in the HVT group (Figure 6.2). The only performance parameter that was found to decrease in the HIT group was velocity$\text{4mM}$ while all other swimming and biomechanical performance parameters remained unchanged. This suggests that a 7 week HIT intervention was neither beneficial nor detrimental to the majority of performance parameters however the HIT group only completed a mean of 6 hours (17.0 km) swimming per week compared to 12 hours (33.4 km) per week for the HVT group. Therefore, the HIT programme was more time efficient as it involved 50% less training time and distance. This could be of benefit to youth athletes who may have limited training time due to school timetables, exam periods or participation in multiple sporting activities.

This study is the longest duration HIT intervention in competitive youth swimmers as previous studies in this cohort had a duration of 4 – 5 weeks (Faude et al. 2008, Sperlich et al. 2010). Faude et al. (2008) compared the effect of a 4 week HIT and HVT intervention on performance in regional to national level swimmers (16.6 ± 1.4 years). The HIT and HVT groups both experienced significant increases in velocity at anaerobic threshold (velocity$\text{\text{threshold}}$) however, there was no change to swimming performance over 100 and 400 m in either groups. The findings of our study indicate that velocity$\text{4mM}$, a similar measure to velocity$\text{\text{threshold}}$, decreased in the HIT group and increased in the HVT group (Figure 6.2). However, the decrease in velocity$\text{4mM}$ in the HIT group did not result in a decrease to 50, 200 or 400 m swimming performance. This is an interesting finding as velocity$\text{4mM}$ is an indicator of aerobic capacity which is important for the more aerobic dependent 200 and 400 m swimming events (Zamparo et al. 2000). Similarly, the increase in velocity$\text{4mM}$ in the HVT group did not result in an increase in swimming performance. Perhaps if the present study and the study by Faude et al. (2008) were of a longer training duration, the changes to velocity$\text{4mM}$ may have influenced swimming performance. However, it is worth noting that previous studies have found varied responses of velocity$\text{4mM}$ and velocity$\text{\text{threshold}}$ to HIT and HVT interventions (Laursen and Jenkins 2002, Stoggl and Sperlich 2014, Stoggl and Sperlich 2015).
Sperlich et al. (2010) compared the effect of a 5 week HIT and HVT intervention on performance in regional swimmers (10.5 ± 1.4 years). The HIT and HVT groups both experienced large and similar increases in performance parameters such as $\dot{V}O_2\text{peak}$, $BLa\text{peak}$ and swim performance across 50 to 2,000 m events. The results indicate that both the HIT and HVT programmes had similar effects however, the HIT group performed 50% less training volume per week, similar to our study. In the present study, a main effect of time for $50_{\text{freestyle}}$ was observed, which suggests there was a difference over time if the group the participants were in and the sex of participants were accounted for. In addition, a borderline main effect of time for $200_{\text{freestyle}}$ was found. However no significant three or two-way interactions were found for $50_{\text{freestyle}}$ and $200_{\text{freestyle}}$. The improvements found in both groups of the Sperlich et al. (2010) study could be expected in a very young cohort (10.5 ± 1.4 years) with limited training experience (~4 swim sessions per week). The cohort of youth swimmers in our study were older (15.8 ± 1.0 years), had higher training experience (6 – 7 swim sessions per week) and were all competing at national level. Therefore, it could be anticipated that improving performance over a relatively short period of time would be more challenging particularly during the third preparation training phase of the season.

To the best of the authors’ knowledge, this study is the first to investigate the effects of a HIT intervention on biomechanical performance parameters in competitive swimmers. The findings indicate both $SL_{50}$ and $SI_{50}$ decreased in the HVT group (Figure 6.2). Stroke length and SI have been found to be one of the best determinants of swimming performance in youth swimmers (Jürimäe et al. 2007, Barbosa et al. 2010b, Mezzaroba and Machado 2014) therefore optimising the development of these parameters is crucial. In addition, the findings are in contrast to the recommendations of expert swimming coaches who suggest HVT programmes optimise stroke mechanics (Greyson et al. 2010, Nugent et al. 2017). These results were slightly unexpected as the HVT group trained as normal so the authors anticipated no change in biomechanical performance. However medium to large effect sizes ($\eta_p^2 = \geq 0.06$ and $\geq 0.15$ respectively, Table 6.4) were found in the time by group interactions for the remaining biomechanical parameters ($SR_{50}$, $SR_{400}$, $SL_{400}$, $SI_{400}$), in combination with no significant changes. This suggests that a greater sample size may have provided more significant findings and thus a clearer picture.
While this study has added to the current literature on this topic, a number of limitations must be noted. Firstly, accurately quantifying the distribution of training volume in different training zones is challenging particularly in an aquatic sport due to the difficulties associated with recording HR underwater and varied metabolic responses to different strokes and technical drills (Barbosa et al. 2006, Rodríguez 2016). In order to reduce any error associated with training zone prescriptions, the lead author was present during all sessions and detailed individual responses to 10 random training sessions were collected for each group (Table 6.2). The measurement of individual responses to HIT and HVT training sessions has not been conducted in previous swimming HIT studies (Faude et al. 2008, Kilen et al. 2014, Pugliese et al. 2015). Secondly, there may be the possibility of parallax error (i.e. the error associated with the apparent position of an object when viewed from a different angle) due to the use of a single-camera analysis system during pre-post biomechanical performance testing. However a multi-camera analysis system was not available during testing and the more widely utilised single-camera analysis system has been shown to be as accurate (Tor et al. 2012). Thirdly, the short duration of this study is a limitation. A systematic review of this topic by Nugent et al. (2016) identified two longitudinal studies of 1 year and 4 years duration which found that HIT improved performance in competitive swimmers. However, there are numerous methodological flaws associated with both studies such as the lack of an appropriate control group.

6.6 Conclusion

The main findings of this study could be of use to coaches and sport scientists who are working with youth athletes that may have limited training time due to school timetables, participation in multiple sports or the commonly restricted training hours for competitive swimming clubs in public facilities. In addition, the lower training volume of a HIT programme may potentially help to reduce the risk of overuse injury. The HIT programme was more time efficient involving a mean training volume of 6 hours (17.0 km) per week whereas the HVT programme had a mean training volume of 12 hours (33.4 km) per week. The findings demonstrate that a 7 week HIT intervention involving a 50% reduction in zone 1 training volume and a 200% increase in zone 3 training volume had neither a beneficial nor detrimental effect on the majority of performance parameters compared to a traditional HVT programme. Velocity\textsubscript{4mM} decreased in the HIT group and increased in the HVT group while both SL\textsubscript{50} and SI\textsubscript{50} decreased in the HVT group. Therefore, the only performance parameter that was found to decrease in
the HIT group was velocity_{4mM} while all other parameters remained unchanged. The decreases in SL_{50} and SI_{50} in the HVT group are of concern and appear to suggest that a HIT programme may be a better option to optimise biomechanical performance. Despite this, more research is needed in this area. Future studies should be of > 12 weeks duration with larger sample sizes and should investigate the effect of HIT and HVT on similar performance parameters.
Chapter 7: Summary, Conclusion and Recommendations
7.1 Summary

The aim of this thesis was to investigate the effects of HIT and HVT on performance in competitive swimmers. In order to address this, the thesis was divided into four distinct but inter-related studies comprising of: a systematic review (Study 1); a mixed-methods study (Study 2); an observational study (Study 3) and an intervention study (Study 4). To the best of the author’s knowledge, Study 1, 2 and 3 (Chapter 3, 4 and 5) were the first studies conducted in their respective areas while Study 4 (Chapter 6) adds to the limited body of scientific literature available investigating the impact of HIT in competitive youth swimmers. To date, Study 4 is the longest intervention study investigating the effects of HIT on performance parameters in competitive youth swimmers.

Study 1 reviewed the extent and quality of the current research literature in order to determine the effects of HIT on physiological performance and swimming performance in competitive swimmers. This systematic review was warranted, due to the extensive debate and controversy of the topic among the swimming community (Stott 2012b, Stott 2012a, Stott 2014, Beliaev 2015, Carlile 2015, Rushall 2015, Salo 2015, Goldsmith 2016, Stott 2016). The review found seven eligible studies on competitive swimmers across a range of cohorts. A recent literature search for updated studies in this area revealed that no additional studies have been published on this topic since conducting Study 1, apart from Study 4 which formed part of this PhD thesis and would have been eligible for the review. In Study 1, two of the eligible studies were conducted on youth swimmers while five studies were conducted on senior swimmers (i.e. elite, university and master swimmers). In youth swimmers, a HIT intervention resulted in significant improvements to physiological performance (aerobic and anaerobic outcome measures) in both studies while significant improvements to swimming performance (50, 100 and 2,000 m) were only evident in one study. In senior swimmers, a HIT intervention resulted in significant improvements to physiological performance, both aerobic and anaerobic, in four of the eligible studies while significant improvements to swimming performance (50 – 1,650 yard) were evident in three studies. However, none of the seven eligible studies involving youth or senior swimmers resulted in a reduction in physiological or swimming performance following a HIT intervention. None of the reviewed studies investigated biomechanical parameters which are consistently shown to be one of the best determinants of swimming performance (Jürimäe et al. 2007, Barbosa et al. 2010b, Mezzaroba and Machado 2014). This is perhaps one of the
principal incentives for undertaking high training volumes in youth swimmers as swimming coaches suggest that large amounts of practice are required to develop efficient stroke mechanics (Greyson et al. 2010) particularly in youth swimmers who need time to develop their technical capacity. Therefore, the next study (Study 2) in this thesis collected both quantitative and qualitative data on current coaching philosophies and training practices amongst elite Irish swimming coaches in order to create further understanding of this topic from an applied coaching perspective.

Study 2 explored expert swimming coaches’ perceptions of quality (HIT) and quantity (HVT) coaching philosophies in competitive swimming and investigated their current training practices. The main findings of this mixed methods study were that coaches felt quality training programmes would lead to short-term results for youth swimmers but were in many cases more appropriate for senior swimmers. The coaches suggested that quantity training programmes build an aerobic base for youth swimmers, promote technical development through a focus on slower swimming and help to enhance recovery from training or competition. However, the coaches continuously suggested that quantity training programmes must be performed with good technique and they felt this was a misunderstood element. The coaches in this study suggested that quantity (HVT) training programmes were more appropriate for youth swimmers therefore the next study (Study 3) in this thesis investigated a period of increased training volume or quantity training.

Study 3 investigated the effects of increased training volume during a 10 day training camp on competitive performance in youth swimmers. In addition, this study investigated the effects of increased training volume (HVT) on ITL and compared coach and swimmers’ RPE throughout the training camp. The main finding of this study was that a 36% increase in swimming volume resulted in significant increases in competitive performance. The increased training volume resulted in significant changes to ITL, specifically session-RPE and the RESTQ-Sport questionnaire, and coaches were found to underestimate swimmers’ RPE for moderate training sessions (RPE 3 – 5) during the camp. Despite the positive findings of this study, which suggest that a period of increased training volume improved competitive performance, the next study (Study 4) in this thesis investigated the effects of a HIT intervention. The reasoning for investigating a HIT intervention over a HVT intervention was due to the fact that research is limited in this area and potentially a HIT intervention may have many
additional benefits to youth swimmers such as reducing the traditionally high training volumes which may help to reduce the likelihood of early sport specialisation, overtraining syndrome and overuse injuries. In addition, a HIT intervention may be more logistically viable as a HIT intervention would involve a reduction in the current training volume of participants whereas a HVT intervention would involve an increase in the current training volume. Therefore, a longitudinal HVT intervention would be very difficult to conduct in a youth cohort due to limited training hours as a result of school scheduling, training facility access, etc.

Study 4 investigated the effects of a 7 week HIT intervention on physiological, biomechanical and swimming performance parameters in national level youth swimmers. The main finding of this study was that a 7 week HIT intervention resulted in a decrease in velocity4mM in the HIT group and an increase in the HVT group while both SL50 and SI50 decreased in the HVT group. Therefore, the only performance parameter that was found to decrease in the HIT group was velocity4mM while all other parameters remained largely unchanged. This suggests that a 7 week HIT intervention was neither beneficial nor detrimental to the majority of performance parameters however the HIT group only completed a mean of 6 hours (17.8 km) swimming per week compared to 12 hours (33.4 km) per week for the HVT group. Therefore, the HIT programme was more time efficient as it involved 50% less training time and 47% less distance. In addition, there were no signs of overtraining syndrome or overuse injury in the HIT group throughout the 7 week intervention despite the 200% increase in zone 3 training. This finding is based on unpublished data from Study 4 which indicates that there were no significant changes in the total stress or recovery scales of the RESTQ-Sport questionnaire over the duration of the intervention (see Appendix 4). The findings of this study are similar to those of previous studies on youth swimmers (Faude et al. 2008, Sperlich et al. 2010), however both studies were conducted over a maximum of 5 weeks duration. The present study therefore adds to the current literature by expanding the intervention duration by 2 weeks. In addition, this study was the first HIT intervention to include outcome measures of biomechanical performance which have been consistently found to be amongst the best determinants of swimming performance (Jüirimäe et al. 2007, Barbosa et al. 2010b, Mezzaroba and Machado 2014). Finally, this study provided in-depth data on the individual responses of participants to HIT and HVT sessions in order to accurately quantify the training completed during the study. This was not conducted in previous HIT studies in swimming (Faude et al. 2008, Kilen
et al. 2014, Pugliese et al. 2015) and is vital due to the potential for varied metabolic responses to different strokes and technical drills (Barbosa et al. 2006, Rodriguez 2016).

7.2 Conclusion
This thesis has contributed several novel findings to the current literature on the HIT versus HVT debate in competitive swimming. The specific conclusions that can be drawn from the four studies are as follows:

- Based on a systematic review of the current literature, the effects of HIT on performance in competitive swimmers is promising however it is difficult to draw accurate conclusions until further research has been conducted (Study 1, Chapter 3).

- A richer and broader understanding on the debate over Quality versus Quantity was gained from the experiential knowledge of expert swimming coaches (Study 2, Chapter 4).

- A 36% increase in swimming training volume during a 10 day training camp resulted in significant changes to competitive performance in youth swimmers (Study 3, Chapter 5).

- A 7 week HIT intervention was neither beneficial nor detrimental to performance parameters in competitive youth swimmers however the HIT group completed 6 hours (17.8 km) of swimming per week compared to 12 hours (33.4 km) per week for the HVT group (Study 4, Chapter 6).

7.3 Limitations
The specific limitations of each study have been previously mentioned in Chapter 3, 4, 5 and 6. The limitations of this thesis as a whole are provided below:

- **Population specificity of results.** Study 2 was conducted on 11 expert swimming coaches from Ireland and therefore the results are specific to an Irish swimming context. A wider recruitment of expert swimming coaches across a number of countries may have provided more in dept findings. Study 3 and 4
were conducted on youth swimmers (15.2 ± 1.3 years and 15.8 ± 1.0 years, respectively) from the senior team of a local swimming club who were competing at the top tier national level (Division 1) and therefore the results are specific to this athletic cohort. Swimming is widely acknowledged as an early specialisation sport and consequently it is difficult to recruit a large sample size of mature swimmers (18+ years), particularly at club level. Despite this, the results of Study 1 and 2 are applicable to a wider range of competitive swimmers – youth, university, elite and masters level.

- **Lack of longitudinal data.** The short duration of the two training studies are a potential limitation of this thesis. Study 3 was conducted over a 10 day period where training volume was increased by 36% during a training camp. Studies of this nature are difficult to conduct in swimming as the majority of swimming clubs are required to rent swimming lanes at an hourly rate from public facilities. Therefore, there are financial limitations surrounding periods of increased training volume or HVT interventions in swimming. Study 4 was conducted over 7 weeks and unfortunately it was not possible to conduct a longer duration study due to the training and competition structure of the season. In addition, conducting a crossover design in order to investigate the effects of a HVT intervention was not possible due to a limited intervention window in a busy competitive season for participants.

- **Training-intensity distribution.** Study 4 involved a 50% decrease in the mean weekly zone 1 (LIT) training volume and a 200% increase in the mean weekly zone 3 (HIT) training volume in the HIT group which was based on the methodology of previous studies (Faude et al. 2008, Kilen et al. 2014, Pugliese et al. 2015). The manipulation of training volume and training zones in Study 4 led to a training-intensity distribution, as described by Seiler (2010), of approximately 81.7% LIT, 1.9% MIT and 16.4% HIT for the HIT group (see Table 6.2, Chapter 6) and 95.8% LIT, 1.2% MIT and 3.0% HIT for the HVT group (see Table 6.2, Chapter 6). The training-intensity distribution of the HIT group in Study 4 is similar to that of a polarized training programme which is defined as a training programme consisting of 75 – 80% LIT, 5% MIT and 15 – 20% HIT (Seiler and Kjerland 2006). This is a limitation of the thesis as there are currently no guidelines available on the specific training-intensity
distribution of a HIT programme. For example, a recent study by Stoggl and Sperlich (2014) investigated the effects of a HIT intervention that had a training-intensity distribution of roughly 43% LIT and 57% HIT. However, the majority of previous HIT interventions do not provide data on the training-intensity distribution and therefore the training-intensity distribution can vary widely which may influence the findings (Laursen et al. 2005, Driller et al. 2009, Akca and Aras 2015, Ni Cheilleachair et al. 2017).

7.4 Practical Applications

This thesis has numerous practical applications for swimming coaches. Based on the findings of Study 1 (Chapter 3) and Study 4 (Chapter 6), the effects of HIT on performance in competitive youth swimmers are promising and there is currently no evidence to suggest that HIT has a negative impact on performance. However, further longitudinal research is needed in this area before more accurate conclusions can be drawn. Potentially, a HIT programme could be more specific to the demands of sprint swimming events that are < 75 seconds duration (e.g. 50 and 100 m) and thus more dependent on anaerobic energy supply (Zamparo et al. 2000, Gastin 2001, Figueiredo et al. 2011). This is in agreement with the expert swimming coaches in Study 2 (Chapter 4) who consistently suggested that quality or HIT programmes were more appropriate for senior sprint swimmers who had already developed good technique and an aerobic base. However, a HIT programme may also have value from a logistical standpoint when swimming coaches have limited training hours available in public facilities or when youth swimmers may not be able to commit to normal training hours due to participation in multiple sports, which is suggested by numerous youth development models (see 2.4.3 Youth development models). For swimming coaches seeking to apply a HIT intervention within their own training programme, some practical recommendations based on the methods utilised in this thesis are provided below:

- Reduce the mean weekly swimming training volume by 40 – 50%, based on the findings of Study 1 (Chapter 3).
- Increase the mean weekly HIT (zone 3) training volume by 50 – 200%, based on the findings of Study 1 (Chapter 3) and Study 4 (Chapter 6).
- Ensure HIT is performed in the correct training zone (i.e. zone 3) through assessing a range of physiological, biomechanical and perceptual responses during training sessions – blood lactate (> 4 mM), HR (> 87% of HR_{max}),
velocity (> LT₁ velocity), stroke rate (> LT₂ stroke rate), session-RPE (≥ 7) and RPE (≥ 17) as described in Study 4 (Chapter 6).

- Example HIT sessions for competitive youth swimmers that were part of the research within this thesis are as follows:
  - 2 × (2 × 25 m maximal effort on 60 s turn around [TA]; 4 × 50 m at 200 m individual race pace [IRP] on 70 s TA; 1 × 50 m maximal effort on 90 s TA; 150 m active recovery) (Study 4, Chapter 6).
  - 6 × 15 m maximal effort on 70 s TA; 3 × (4 × 50 m at 200 m IRP on 60 s TA; 300 m active recovery) (Study 4, Chapter 6).
  - 8 × 50 m at 400 m IRP on 60 s TA; 300 m active recovery; 8 × 50 m at 400 m IRP on 60 s TA (Study 4, Chapter 6).
  - 1 × 200 m at personal best 200 m time (+ 2 s) on 180 s TA; 4 × 50 m at 400 m IRP on 60 s TA; 100 m active recovery; 4 × 50 m at 200 m IRP on 75 s TA (Study 4, Chapter 6).

Based on the findings of Study 3 (Chapter 5), a 36% increase in swimming training volume during a 10 day training camp resulted in significant changes to competitive performance in youth swimmers. This finding is in agreement with the recommendations of the expert swimming coaches in Study 2 (Chapter 4) who continuously suggest that quantity training programmes (i.e. HVT) build an aerobic base for youth swimmers, promote technical development through a focus on slower swimming and help to enhance recovery from training or competition. The majority of swimming events are > 75 seconds duration (e.g. 200, 400, 800, 1,500 and 10,000 m) and thus more dependent on aerobic energy supply (Zamparo et al. 2000, Gastin 2001, Figueiredo et al. 2011), therefore HVT programmes may be appropriate. However, caution is advised when undertaking HVT programmes with youth swimmers particularly if the training volume is in excess of what the individual swimmer (s) can physically and psychologically recover from. For swimming coaches seeking to apply a HVT intervention within their own training programme, some practical recommendations based on the methods utilised in this thesis are provided below:

- Increase the mean weekly LIT (zone 1) training volume by 30 – 36%, based on the findings of Study 1 (Chapter 3) and Study 3 (Chapter 5).
- Ensure LIT is performed in the correct training zone (i.e. zone 1) through assessing a range of physiological, biomechanical and perceptual responses
during training sessions – blood lactate (< 2 mM), HR (< 80% of HR\text{max}), velocity (< LT\text{1} velocity), stroke rate (< LT\text{1} stroke rate), session-RPE (≤ 4) and RPE (≤ 13) as described in Study 4 (Chapter 6).

### 7.5 Future Recommendations

The current scientific literature related to the HIT versus HVT debate in swimming, and the investigation of same, is extremely limited and there is great scope and need for future research in this area. This thesis has made a substantial original contribution in expanding the body of knowledge on this complex and controversial topic. However, there remain a number of unanswered questions within the current scientific literature. Specific recommendations for each individual study of this thesis have been provided in Chapter 3, 4, 5 and 6 however future recommendations of this thesis as a whole are provided below.

- **Longitudinal HIT intervention on competitive youth swimmers.** There is a need from a theoretical and applied standpoint to conduct a longitudinal HIT intervention of > 12 weeks duration on competitive youth swimmers. Currently, the longest duration randomised controlled study on elite swimmers is 12 weeks duration (Kilen et al. 2014) whilst the longest duration randomised controlled studies on youth swimmers are 4 to 5 weeks duration (Faude et al. 2008, Sperlich et al. 2010). In addition, there is currently only one HIT study, by Sperlich et al. (2010), on pre-pubescent swimmers. The topic warrants further research as pre-pubescent athletes have been shown to have a greater resistance to fatigue and greater recovery abilities during high intensity exercise (Hebestreit et al. 1993, Falk and Dotan 2006, Ratel and Blazevich 2017).

- **Case study of HIT intervention on elite swimmer (s).** There is a large amount of anecdotal evidence within swimming magazines, swimming books and among the swimming community to support the fact that HIT programmes are increasingly being used at the elite level, particularly for swimmers who compete in short to middle distance events (Stott 2012b, Stott 2012a, Stott 2014, Beliaev 2015, Carlile 2015, Rushall 2015, Salo 2015, Goldsmith 2016, Stott 2016). However, to the best of the author’s knowledge, no case studies of elite swimmers have been published in peer reviewed journals. The publication of
case studies of this nature would help to create greater understanding of this topic from an applied perspective.

- **Case study or observational study of HVT intervention on competitive swimmer(s).** Due to the financial and logistical constraints associated with conducting HVT interventions in competitive swimming, future research should be directed towards conducting case studies or observational studies of a HVT intervention on an individual or group of competitive swimmers. Competitive swimmers typically increase training volume at multiple stages throughout their career particularly when moving from one training level or squad to another. For example, the swimmers who participated in Study 3 and 4 gradually increased training volume from a mean of 20 km per week to a mean of 35 – 40 km per week, upon transitioning from the junior club team to the senior club team within the swimming club. Anecdotal evidence suggests that this period often results in improved competitive performance across all events. Therefore, further research is required in this area.

- **Sport-specific outcome measures of physiological, biomechanical and swimming performance.** Future HIT and HVT studies should include sport-specific outcome measures of physiological, biomechanical and swimming performance, similar to Study 4. Swimming performance is multi-faceted and utilising a large number of outcome measures promotes a greater understanding of the effects of HIT and HVT interventions. Outcome measures of biomechanical performance are of particular importance in assessing the effectiveness of HIT and HVT interventions, as biomechanical parameters such as SR, SL and SI have been consistently shown to be among the strongest determinants of swimming performance (Jürimäe et al. 2007, Lätt et al. 2010, Mezzaroba and Machado 2014).

- **Training-intensity distribution of a HIT programme.** Future HIT studies should aim to establish the optimal training-intensity distribution of a HIT programme. Study 4 had a training-intensity distribution of approximately 81.7% LIT, 1.9% MIT and 16.4% HIT for the HIT group (see Table 6.2, Chapter 6). The majority of HIT interventions do not provide data on the training-intensity distribution of the intervention and consequently the training-intensity distribution can vary
Chapter 8: References


*FINA points table* (2011) [online], available: [http://www.fina.org/content/fina-points](http://www.fina.org/content/fina-points) [accessed 19 Dec 2016].


Chapter 9: Appendices
Appendix 1: Participant Information Sheets
PARTICIPANT INFORMATION SHEET

Quality versus Quantity Debate in Swimming: Perceptions and Practices of Irish Swimming Coaches

What is the project about?
This research aims to explore the perceptions of Irish swimming coaches on the Quality versus Quantity Debate in competitive swimming and to investigate their current training practices. The Quality versus Quantity Debate is a long standing topic of discussion among swimming coaches and academics. The quality side of the debate suggests that swimming training programs should involve less meters per session, but the swimming repeats should be performed at higher intensities. The quantity side of the debate suggests that swimming programs should be judged by the number of meters swam (i.e. volume) as greater volume will enhance endurance and thus produces faster times. It is hoped that this research can provide further understanding of the topic from an applied coaching perspective.

What will I have to do?
If you agree to volunteer for the study, you will be required to partake in 1 semi-structured interview (maximum duration of 1 hour) and 1 questionnaire (maximum duration of 15 minutes) that will be conducted in a location and at a time of your choice.

What are the benefits?
The benefits are that you will get to voice your opinion on both sides of the debate. This will provide valuable information from an applied coaching perspective which is currently not available in the scientific literature.

What are the risks?
There are no risks associated with participation in this research.

What if I do not want to take part?
You can stop taking part in the research study at any time. Should you feel at any stage that you want to stop taking part in the study, then this is dealt with in a sensitive and confidential manner.

What happens to the information?
The information gathered from the study will be handled in complete confidence. Results of the participants as well as their confidentiality are the first priority of the researchers carrying out the study. The semi-structured interview will be audio recorded with all recordings stored safely, securely and confidentially. The audio recordings will be coded to
protect the identity of the participant. Only researchers in the study will have access to the audio recordings. The questionnaire will also be coded to ensure that the coach and their training practices remain anonymous to the researchers.

Who else is taking part?
A random sample of Irish coaches that have met specific criteria have been invited to take part. The three criteria for inclusion in the study were 1) a minimum of 10 years swimming coaching experience, 2) must currently hold a Level 3 Swim Ireland coaching qualification or the international equivalent and 3) must have coached at least two international level swimmers.

What if something goes wrong?
In the unlikely event that something goes wrong, the testing procedure will immediately stop and the PESS department emergency procedures will be followed.

What happens at the end of the study?
At the end of the study the information will be used to present results but the information will be completely anonymous. All audio-recordings and questionnaires will be held by the principal investigator (Dr Giles Warrington) for up to 7 years on a password-protected computer in UL.

What if I have more questions or do not understand something.
If you do not understand any aspect of the research please contact either investigators (Dr Giles Warrington or Frank Nugent) and discuss any questions that you might have. It is important that you feel completely at ease during the research.

What if I change my mind during the study?
Should you feel at any stage that you want to stop being a participant in the research, you are free to stop and take no further part.

Thank you for taking the time to read this information sheet.

Project Investigator Contact Details:

Principal Investigator
Dr Giles Warrington,
Senior Lecturer,
Physical Education and Sports Sciences Department,
University of Limerick.
Tel (061) 234903
Email: giles.warrington@ul.ie

Other investigators
Frank Nugent,
PhD Researcher,
Physical Education and Sports Sciences Department,
University of Limerick.
Tel 0851506074
Email: frank.nugent@ul.ie

If you have any concerns about this study and wish to contact someone independent, you may contact:
The EHS Research Ethics Contact Point of the Education and Health Sciences Research Ethics Committee, Room E1003, University of Limerick, Limerick.
PARTICIPANT INFORMATION SHEET

Effects of Increased Training Volume during a 10 Day Training Camp on Competitive Performance in National Level Youth Swimmers

What is the project about?
Training camps are traditionally periods where coaches increase training volume with the aim of improving subsequent athletic performance. Monitoring the training program can aid in determining whether an athlete is adapting to the increased training volume while minimizing the risk of developing overtraining, illness and/or injury. Competitive youth swimmers are an athletic population that have been found to be at a high risk of overtraining and early specialisation therefore training programs should be monitored carefully. This research aims to assess the effects of increased training volume during a 10 day training camp on competitive performance in national level youth swimmers.

What will you have to do?
If you agree to partake in this study, you will be required compete in 2 national level swimming competitions (1 pre-camp and 1 post-camp), to fill in a monitoring questionnaire at 4 stages throughout the training camp and to provide ratings of perceived exertion (how hard the session was) following each swimming session.

What are the risks?
There are no risks associated with participation in this research.

What if you do not want to take part in the study?
You can stop taking part in the research study at any time. Should you feel at any stage that you want to stop taking part in the study, this is dealt with in a confidential manner.

What happens to the information?
The information gathered from the study will be handled in complete confidence. The results of the study may be used to write a scientific research paper.

Who else is taking part?
All of the swimmers who are travelling to the NAC training camp in Fuerteventura have been invited to take part.
What if I have more questions or do not understand something.
If you do not understand any aspect of the research please contact either investigators
(Dr Giles Warrington or Frank Nugent) and discuss any questions that you might have.
It is important that you feel completely at ease during the research.

Thank you for taking the time to read this information sheet.

**Project Investigator Contact Details:**

**Principal Investigator**
Dr Giles Warrington,
Senior Lecturer,
Physical Education and Sports Sciences Department,
University of Limerick.
Tel (061) 234903
Email: giles.warrington@ul.ie

**Other investigators**
Frank Nugent,
PhD Researcher,
Physical Education and Sports Sciences Department,
University of Limerick.
Tel 0851506074
Email: frank.nugent@ul.ie

*If you have any concerns about this study and wish to contact someone independent, you may contact:*

*The EHS Research Ethics Contact Point of the Education and Health Sciences Research Ethics Committee, Room E1003, University of Limerick, Limerick.*
PARTICIPANT INFORMATION SHEET

The Effects of Low-Volume, High-Intensity Training on Performance in Competitive Swimmers

What is the project about?
This project aims to investigate the effects of a 7 week low-volume, high-intensity training (HIT) programme on swimming performance. HIT is a training method that involves performing sets of fast swimming and is generally conducted using lower training volumes (i.e. total distance or minutes per session) than normal swimming training. The current scientific evidence suggests that it may be a new and different way to train. All of the studies have shown that HIT is as effective as normal swimming training however more investigation is required.

What will you have to do?
If you agree to participate in this project, then the first step will involve you completing some testing which will be conducted during normal training hours for the National Aquatic Centre (NAC) Senior Squad. This testing will help to show you how fit you are and how good your swimming technique is. This information will help you to develop as a swimmer.

The first stage of the testing protocol involves measuring each swimmers height, weight and body composition. The second stage involves measuring each swimmers fitness level using a 7 × 200 m step test. This test involves performing several evenly paced 200 m swims on a 5 minute cycle, graded from easy to maximal. The seventh 200 m will be swam at each swimmers 200 m personal best time or faster. A swimmers heart rate and blood lactate will be measured following each 200 m of the test. Blood lactate is measured by taking a small blood sample from a swimmers ear lobe. Heart rate and blood lactate show how hard a swimmer is working during each 200 m interval.

The third stage of the testing involves measuring swimming technique during a maximal 50 and 400 m freestyle. Swimming technique will be measured by recording stroke rate, stroke length and stroke efficiency using a video recorder and technique analysis software on a computer.

Following this testing, the NAC senior squad will be randomly divided into a HIT group or a control group. The HIT group will reduce the volume of their normal swimming
routine but with the addition of some extra HIT sets. The control group will train as normal with no additional HIT sets. The final stage in this study involves re-testing all of the participants at the end of the 7 week project.

**What are the risks?**
There are no risks associated with participation in this project. All of the testing will be completed during normal senior training hours in the NAC swimming pool. The full coaching staff with parental supervision will be present during all testing. The testing will be conducted by appropriately qualified individuals.

**What if you do not want to take part in this project?**
You can stop taking part in this project at any time. Should you feel at any stage that you want to stop taking part, this is dealt with in a confidential manner. However, participation in this project requires at least an 80% attendance rate to normal training in the NAC senior squad.

**What happens to the information?**
The information gathered from this project will be handled in complete confidence. The results of this project may be used to write a scientific research paper.

**Who else is taking part?**
Only swimmers from the NAC Senior Squad have been invited to take part.

**What if I have more questions or do not understand something.**
If you do not understand any aspect of the research please contact either Dave Malone or the project investigators (Dr Giles Warrington and Frank Nugent) and discuss any questions that you might have. It is important that you feel completely at ease during the research. Thank you for taking the time to read this information sheet.

**Project Investigator Contact Details:**

**Principal Investigator**
Dr Giles Warrington,
Senior Lecturer,
Physical Education and Sports Sciences Department,
University of Limerick.
Tel (061) 234903
Email: giles.warrington@ul.ie

**Other investigators**
Frank Nugent,
PhD Researcher,
Physical Education and Sports Sciences Department,
University of Limerick.
Tel 0851506074
Email: frank.nugent@ul.ie

*If you have any concerns about this study and wish to contact someone independent, you may contact:*

The EHS Research Ethics Contact Point of the Education and Health Sciences Research Ethics Committee, Room E1003, University of Limerick, Limerick.
Appendix 2: Informed Consent Forms
PARTICIPANT INFORMED CONSENT

Quality versus Quantity Debate in Swimming: Perceptions and Practices of Irish Swimming Coaches

Should you agree to participate in this study please read the statements below and if you agree to them, please sign the consent form.

- I have read and understood the participant information sheet.
- I understand what the study is about, and what the results will be used for.
- I understand that what the researchers find out in this study may be shared with others but that my name will not be given to anyone in any written material developed.
- I know that I am choosing to take part in the study and that I can stop taking part in the study at any stage without giving any reason to the researchers.

This study involves audio recording. Please tick the appropriate box

- I am aware that by participating in this study I will be audio recorded and I agree to this. However, if I feel uncomfortable at any time I can ask that the recording equipment be switched off. I understand that I can ask for a copy of my recording. I understand what will happen to the recordings once the study is finished.

- I do not agree to be audio recorded in this study.

After considering the above statements, I consent to my involvement in this research study.

Name: (please print): ____________________________
Signature: ____________________________ Date: ____________
Investigator’s Signature: ____________________________ Date: ____________
PARTICIPANT INFORMED CONSENT

Effects of Increased Training Volume during a 10 Day Training Camp on Competitive Performance in National Level Youth Swimmers

Should you agree to participate in this study please read the statements below and if you agree to them, please sign the consent form.

- I have read and understood the participant information sheet.
- I understand what the study is about, and what the results will be used for.
- I am fully aware of what I will have to do.
- I know that I am choosing to take part in the study and that I can stop taking part in the study at any stage without giving any reason to the researchers.

After considering the above statements, I consent to my involvement in this research study.

Name: (please print): __________________________
Participant’s Signature: __________________________ Date: __________
Guardian’s Signature: __________________________ Date: __________
Investigator’s Signature __________________________ Date: __________
PARTICIPANT INFORMED CONSENT

The Effects of Low-Volume, High-Intensity Training on Performance in Competitive Swimmers

Should you agree to participate in this study please read the statements below and if you agree to them, please sign the consent form.

- I have read and understood the participant information sheet.
- I understand what the study is about, and what the results will be used for.
- I am fully aware of what I will have to do.
- I know that I am choosing to take part in the study and that I can stop taking part in the study at any stage without giving any reason to the researchers.

After considering the above statements, I consent to my involvement in this research study.

Name: (please print): __________________________

Participant’s Signature: __________________________ Date: ______________

Guardian’s Signature: __________________________ Date: ______________

Investigator’s Signature: __________________________ Date: ______________
Appendix 3: Questionnaire
QUESTIONNAIRE

The aim of this questionnaire is to establish the current training practices of Irish swimming coaches for each competitive stage of the Swim Ireland Aquatic Pathway.

- Swim Skills Stage (Males 9 – 12 years and Females 8 – 11 years)
- Training to Train Stage (Males 12 – 15 years and Females 11 – 14 years)
- Training to Compete Stage (Males 15 – 18 years and Females 14 – 16 years)
- Training to Win Stage (Males 18 + years and Females 16 + years)

The questionnaire is divided into 4 sections, with the same questions asked in each section and should take a maximum of 15 minutes to complete. Confidentiality of your answers will be ensured through coding of your interview transcripts with your questionnaire, therefore your answers and identity will remain anonymous.

*Please note: While providing an answer for each question please ensure that you select your current or previous training prescriptions for each level of swimmers.

Participant ID number: ______________
SECTION 1 – SWIM SKILLS STAGE*

* Males 9 – 12 years and Females 8 – 11 years

1. On average, how many days per week should swimmers at the Swim Skills stage of development spend practicing in the pool? Please tick one option.

   - 2 days per week
   - 3 days per week
   - 4 days per week
   - 5 days per week
   - 6 days per week
   - 7 days per week

2. On average, how many sessions per week should swimmers at the Swim Skills stage of development spend practicing in the pool? In your response to this question, do not include sessions spent on other training like dry land. Please tick one option.

   - Less than 3 sessions per week
   - 3 – 5 sessions per week
   - 6 – 8 sessions per week
   - 9 – 11 sessions per week
   - 12 - 14 sessions per week
   - Greater than 14 sessions per week

3. On average, how many minutes per session should swimmers at the Swim Skills stage of development spend practicing in the pool? In your response to this question, do not include time spent on other training like dry land. Please tick one option.

   - Less than 30 minutes per session
   - 30 - 60 minutes per session
   - 61 – 90 minutes per session
   - 91 – 120 minutes per session
   - Greater than 121 minutes per session

4. On average, how many hours per week should swimmers at the Swim Skills stage of development spend practicing in the pool? In your response to this question, do not include time spent on other training like dry land. Please tick one option.

   - Less than 5 hours per week
   - 5 – 10 hours per week
   - 11 – 15 hours per week
   - 16 – 20 hours per week
   - 21 – 25 hours per week
   - Greater than 25 hours per week
5. On average, how many metres per week should swimmers at the Swim Skills stage of development spend practicing in the pool? Please tick one option.
   - Less than 5,000 meters per week
   - 5,001 – 10,000 meters per week
   - 10,001 – 15,000 meters per week
   - 15,001 – 20,000 meters per week
   - 20,001 – 25,000 meters per week
   - 25,001 – 30,000 meters per week
   - 30,001 – 35,000 meters per week
   - 35,001 – 40,000 meters per week
   - 40,001 – 45,000 meters per week
   - 45,001 – 50,000 meters per week
   - 50,001 – 55,000 meters per week
   - 55,001 – 60,000 meters per week
   - 60,001 – 65,000 meters per week
   - 65,001 – 70,000 meters per week
   - Greater than 70,001 meters per week

6. On average, how many metres per session should swimmers at the Swim Skills stage of development spend practicing in the pool? Please tick one option.
   - Less than 1,000 meters per session
   - 1,001 – 2,000 meters per session
   - 2,001 – 3,000 meters per session
   - 3,001 – 4,000 meters per session
   - 4,001 – 5,000 meters per session
   - 5,001 – 6,000 meters per session
   - 6,001 – 7,000 meters per session
   - 7,001 – 8,000 meters per session
   - 8,001 – 9,000 meters per session
   - 9,001 – 10,000 meters per session
   - Greater than 10,001 meters per session

7. In your opinion, what energy systems are important at the Swim Skills stage of development? Please rank 1 - 3 in order of importance (1 = most important).
   - Aerobic energy system: _______
   - Anaerobic energy system: _______
   - ATP-CP energy system: _______

8. “A Quality based training philosophy is necessary for swimmers at the Swim Skills stage of development”. Please tick one option that best describes how you feel about this statement.
   - Strongly disagree
   - Disagree
   - Undecided
   - Agree
   - Strongly agree
9. “A Quantity based training philosophy is necessary for swimmers at the Swim Skills stage of development.” Please tick one option that best describes how you feel about this statement.

   o Strongly disagree
   o Disagree
   o Undecided
   o Agree
   o Strongly agree

SECTION 2 – TRAINING TO TRAIN STAGE*

* Males 12 – 15 years and Females 11 – 14 years

1. On average, how many days per week should swimmers at the Training to Train stage of development spend practicing in the pool? Please tick one option.

   o 2 days per week
   o 3 days per week
   o 4 days per week
   o 5 days per week
   o 6 days per week
   o 7 days per week

2. On average, how many sessions per week should swimmers at the Training to Train stage of development spend practicing in the pool? In your response to this question, do not include sessions spent on other training like dry land. Please tick one option.

   o Less than 3 sessions per week
   o 3 – 5 sessions per week
   o 6 – 8 sessions per week
   o 9 – 11 sessions per week
   o 12 – 14 sessions per week
   o Greater than 14 sessions per week

3. On average, how many minutes per session should swimmers at the Training to Train stage of development spend practicing in the pool? In your response to this question, do not include time spent on other training like dry land. Please tick one option.

   o Less than 30 minutes per session
   o 30 – 60 minutes per session
   o 61 – 90 minutes per session
   o 91 – 120 minutes per session
   o Greater than 121 minutes per session
4. On average, how many hours per week should swimmers at the Training to Train stage of development spend practicing in the pool? In your response to this question, do not include time spent on other training like dry land. Please tick one option.

- Less than 5 hours per week
- 5 – 10 hours per week
- 11 – 15 hours per week
- 16 – 20 hours per week
- 21 – 25 hours per week
- Greater than 25 hours per week

5. On average, how many metres per week should swimmers at the Training to Train stage of development spend practicing in the pool? Please tick one option.

- Less than 5,000 meters per week
- 5,001 – 10,000 meters per week
- 10,001 – 15,000 meters per week
- 15,001 – 20,000 meters per week
- 20,001 – 25,000 meters per week
- 25,001 – 30,000 meters per week
- 30,001 – 35,000 meters per week
- 35,001 – 40,000 meters per week
- 40,001 – 45,000 meters per week
- 45,001 – 50,000 meters per week
- 50,001 – 55,000 meters per week
- 55,001 – 60,000 meters per week
- 60,001 – 65,000 meters per week
- 65,001 – 70,000 meters per week
- Greater than 70,001 meters per week

6. On average, how many metres per session should swimmers at the Training to Train stage of development spend practicing in the pool? Please tick one option.

- Less than 1,000 meters per session
- 1,001 – 2,000 meters per session
- 2,001 – 3,000 meters per session
- 3,001 – 4,000 meters per session
- 4,001 – 5,000 meters per session
- 5,001 – 6,000 meters per session
- 6,001 – 7,000 meters per session
- 7,001 – 8,000 meters per session
- 8,001 – 9,000 meters per session
- 9,001 – 10,000 meters per session
- Greater than 10,001 meters per session
7. In your opinion, what energy systems are important at the Training to Train stage of development? Please rank 1 - 3 in order of importance (1 = most important).
   - Aerobic energy system: _______
   - Anaerobic energy system: _______
   - ATP-CP energy system: _______

8. “A Quality based training philosophy is necessary for swimmers at the Training to Train stage of development”. Please tick one option that best describes how you feel about this statement.
   - Strongly disagree
   - Disagree
   - Undecided
   - Agree
   - Strongly agree

9. “A Quantity based training philosophy is necessary for swimmers at the Training to Train stage of development.” Please tick one option that best describes how you feel about this statement.
   - Strongly disagree
   - Disagree
   - Undecided
   - Agree
   - Strongly agree

SECTION 3 – TRAINING TO COMPETE*

* Males 15 – 18 years and Females 14 – 16 years

1. On average, how many days per week should swimmers at the Training to Compete stage of development spend practicing in the pool? Please tick one option.
   - 2 days per week
   - 3 days per week
   - 4 days per week
   - 5 days per week
   - 6 days per week
   - 7 days per week
2. On average, how many sessions per week should swimmers at the Training to Compete stage of development spend practicing in the pool? In your response to this question, do not include sessions spent on other training like dry land. Please tick one option.

- Less than 3 sessions per week
- 3 – 5 sessions per week
- 6 – 8 sessions per week
- 9 – 11 sessions per week
- 12 – 14 sessions per week
- Greater than 14 sessions per week

3. On average, how many minutes per session should swimmers at the Training to Compete stage of development spend practicing in the pool? In your response to this question, do not include time spent on other training like dry land. Please tick one option.

- Less than 30 minutes per session
- 30 – 60 minutes per session
- 61 – 90 minutes per session
- 91 – 120 minutes per session
- Greater than 121 minutes per session

4. On average, how many hours per week should swimmers at the Training to Compete stage of development spend practicing in the pool? In your response to this question, do not include time spent on other training like dry land. Please tick one option.

- Less than 5 hours per week
- 5 – 10 hours per week
- 11 – 15 hours per week
- 16 – 20 hours per week
- 21 – 25 hours per week
- Greater than 25 hours per week

5. On average, how many metres per week should swimmers at the Training to Compete stage of development spend practicing in the pool? Please tick one option.

- Less than 5,000 meters per week
- 5,001 – 10,000 meters per week
- 10,001 – 15,000 meters per week
- 15,001 – 20,000 meters per week
- 20,001 – 25,000 meters per week
- 25,001 – 30,000 meters per week
- 30,001 – 35,000 meters per week
- 35,001 – 40,000 meters per week
- 40,001 – 45,000 meters per week
6. On average, how many metres per session should swimmers at the Training to Compete stage of development spend practicing in the pool? Please tick one option.

- Less than 1,000 meters per session
- 1,001 – 2,000 meters per session
- 2,001 – 3,000 meters per session
- 3,001 – 4,000 meters per session
- 4,001 – 5,000 meters per session
- 5,001 – 6,000 meters per session
- 6,001 – 7,000 meters per session
- 7,001 – 8,000 meters per session
- 8,001 – 9,000 meters per session
- 9,001 – 10,000 meters per session
- Greater than 10,001 meters per session

7. In your opinion, what energy systems are important at the Training to Compete stage of development? Please rank 1 - 3 in order of importance (1 = most important).

- Aerobic energy system: _______
- Anaerobic energy system: _______
- ATP-CP energy system: _______

8. “A Quality based training philosophy is necessary for swimmers at the Training to Compete stage of development”. Please tick one option that best describes how you feel about this statement.

- Strongly disagree
- Disagree
- Undecided
- Agree
- Strongly agree

9. “A Quantity based training philosophy is necessary for swimmers at the Training to Compete stage of development.” Please tick one option that best describes how you feel about this statement.

- Strongly disagree
- Disagree
- Undecided
SECTION 4 – TRAINING TO WIN*

*Males 18+ years and Females 16+ years

1. On average, how many days per week should swimmers at the Training to Win stage of development spend practicing in the pool? Please tick one option.
   - 2 days per week
   - 3 days per week
   - 4 days per week
   - 5 days per week
   - 6 days per week
   - 7 days per week

2. On average, how many sessions per week should swimmers at the Training to Win stage of development spend practicing in the pool? In your response to this question, do not include sessions spent on other training like dry land. Please tick one option.
   - Less than 3 sessions per week
   - 3 – 5 sessions per week
   - 6 – 8 sessions per week
   - 9 – 11 sessions per week
   - 12 – 14 sessions per week
   - Greater than 14 sessions per week

3. On average, how many minutes per session should swimmers at the Training to Win stage of development spend practicing in the pool? In your response to this question, do not include time spent on other training like dry land. Please tick one option.
   - Less than 30 minutes per session
   - 30 – 60 minutes per session
   - 61 – 90 minutes per session
   - 91 – 120 minutes per session
   - Greater than 121 minutes per session

4. On average, how many hours per week should swimmers at the Training to Win stage of development spend practicing in the pool? In your response to this question, do not include time spent on other training like dry land. Please tick one option.
   - Less than 5 hours per week
   - 5 – 10 hours per week
   - 11 – 15 hours per week
5. On average, how many metres per week should swimmers at the Training to Win stage of development spend practicing in the pool? Please tick one option.

- Less than 5,000 meters per week
- 5,001 – 10,000 meters per week
- 10,001 – 15,000 meters per week
- 15,001 – 20,000 meters per week
- 20,001 – 25,000 meters per week
- 25,001 – 30,000 meters per week
- 30,001 – 35,000 meters per week
- 35,001 – 40,000 meters per week
- 40,001 – 45,000 meters per week
- 45,001 – 50,000 meters per week
- 50,001 – 55,000 meters per week
- 55,001 – 60,000 meters per week
- 60,001 – 65,000 meters per week
- 65,001 – 70,000 meters per week
- Greater than 70,001 meters per week

6. On average, how many metres per session should swimmers at the Training to Win stage of development spend practicing in the pool? Please tick one option.

- Less than 1,000 meters per session
- 1,001 – 2,000 meters per session
- 2,001 – 3,000 meters per session
- 3,001 – 4,000 meters per session
- 4,001 – 5,000 meters per session
- 5,001 – 6,000 meters per session
- 6,001 – 7,000 meters per session
- 7,001 – 8,000 meters per session
- 8,001 – 9,000 meters per session
- 9,001 – 10,000 meters per session
- Greater than 10,001 meters per session

7. In your opinion, what energy systems are important at the Training to Win stage of development? Please rank 1 - 3 in order of importance (1 = most important).

- Aerobic energy system: ______
- Anaerobic energy system: ______
- ATP-CP energy system: ______

8. “A Quality based training philosophy is necessary for swimmers at the Training to Win stage of development”. Please tick one option that best describes how you feel about this statement.
9. “A Quantity based training philosophy is necessary for swimmers at the Training to Win stage of development.” Please tick one option that best describes how you feel about this statement.

- Strongly disagree
- Disagree
- Undecided
- Agree
- Strongly agree

Thank you for participating in this questionnaire.
Appendix 4: Unpublished RESTQ-Sport Questionnaire Data
Descriptive statistics of the RESTQ-Sport questionnaire scales for the HIT and HVT group (n = 15)

<table>
<thead>
<tr>
<th>Variables</th>
<th>HIT (n = 7)</th>
<th>HVT (n = 8)</th>
<th>ANOVA p values and Effect Sizes (η²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Week 1</td>
<td>Week 3</td>
<td>Week 5</td>
</tr>
<tr>
<td>Total stress score</td>
<td>17.51 ± 8.69</td>
<td>17.68 ± 5.28</td>
<td>16.27 ± 6.93</td>
</tr>
<tr>
<td>Total recovery score</td>
<td>31.21 ± 6.74</td>
<td>32.19 ± 5.53</td>
<td>32.07 ± 8.06</td>
</tr>
</tbody>
</table>

Values are mean ± SD

Total recovery score (sum of the scales 8 – 12 and 16 – 19) and total stress score (sum of the scales 1 – 7 and 13 – 15)
Appendix 5: Published Journal Articles and Conference Presentations
Effects of Low-Volume, High-Intensity Training on Performance in Competitive Swimmers: A Systematic Review

Frank J. Nugent, Thomas M. Comyns, Emma Burrows, and Giles D. Warrington

Abstract

Nugent, FJ, Comyns, TM, Burrows, E, and Warrington, GD. Effects of low-volume, high-intensity training on performance in competitive swimmers: a systematic review. J Strength Cond Res 31(3): 837-847, 2017—The purpose of this systematic review was to examine the extent and quality of the current research literature to determine the effects of low-volume, high-intensity training (HIT) on physiological performance and swimming performance in competitive swimmers. The methodology followed the preferred reporting items for systematic review and meta-analysis protocol. A search of relevant databases and conference proceedings was performed until December 2015. The inclusion criteria were (a) competitive swimmers, (b) ≥4 weeks HIT intervention, (c) comparison group had to involve a higher training volume, (d) outcomes measures of physiological and swimming performance, and (e) all experimental study designs. Quality assessment was performed using the Quality Index checklist. Results indicate that of the 538 studies retrieved, 7 studies met the inclusion criteria. Six of the 7 studies found that an HIT intervention resulted in significant improvements in physiological performance. Four of the 7 studies found that HIT resulted in significant improvements in swimming performance, whereas none of the 7 studies resulted in a reduction in physiological or swimming performance. Despite the positive findings of this review, the short study duration is a limitation to a number of studies. The current evidence on the effects of HIT on performance is promising; however, it is difficult to draw accurate conclusions until further research has been conducted.

Key Words: swimming, HIT, HIT, physiological performance, swimming performance

Introduction

Swimming has been part of the Olympic programme since the establishment of the first modern Olympic Games in 1896. Over this time, the sport has progressed to become one of the largest Olympic sports with 32 pool events ranging in distance from 50 to 1500 meters. The Gold Medal winning times at the London 2012 Olympics ranged in duration from 21.34 seconds for the 50-m event to approximately 14 minutes 31.82 seconds for the 1500-m event. Twenty-six of 32 (81%) Olympic level swimming events are competet over a race distance of 200 m or less, for a typical duration of less than 2 minutes 20 seconds.

Swimming coaches are widley acknowledged to place a strong emphasis on developing a swimmer’s aerobic energy system throughout their career through the use of low-intensity aerobic training. This is a common training practice across all age cohorts and swimming events (43,45). Greyson et al. (23) suggest that developing the aerobic energy system in swimmers is crucial to improve recovery from high-intensity training (HIT) sets and competition, to maximize the development of the diaphragm and thorax during manuater, and to target the optimal window for aerobic development as proposed in the Long Term Athlete Development (LTAD) model (4).

Swimming coaches typically prescribe low-intensity aerobic training in large quantities with the aim of enhancing swimming performance, this is commonly referred to as high-volume training (HVT). The relevance of HVT to the physiological requirements of many swimming events has been questioned in the scientific literature (3,10,11,30,56), as 81% of Olympic level events are competed over 200 m or less, for a typical duration of less than 2 minutes 20 seconds. This issue is a long-standing topic of discussion among swimming coaches (22,57,64-66) and has been referred to as the “Quality vs. Quantity debate” (44,58). On the quality side of the debate, there is the suggestion that the focus on the swimming program should be on low-volume training at high intensities, whereas the quantity side suggests that HVT at lower intensities will enhance swimming performance (44,58). The recent success of competitive swimmers who train using the Ultra-Short
Quality Versus Quantity Debate in Swimming: Perceptions and Training Practices of Expert Swimming Coaches

by
Frank J. Nugent¹, Thomas M. Comyns¹, Giles D. Warrington¹

The debate over low-volume, high-intensity training versus high-volume, low-intensity training, commonly known as Quality versus Quantity, respectively, is a frequent topic of discussion among swimming coaches and academics. The aim of this study was to explore expert coaches’ perceptions of quality and quantity coaching philosophies in competitive swimming and to investigate their current training practices. A purposeful sample of 11 expert swimming coaches was recruited for this study. The study was a mixed methods design and involved each coach participating in a semi-structured interview and completing a closed-ended questionnaire. The main findings of this study were that coaches felt quality training programmes would lead to short term results for youth swimmers, but were in many cases more appropriate for senior swimmers. The coaches suggested that quantity training programmes built an aerobic base for youth swimmers, promoted technical development through a focus on slower swimming and helped to enhance recovery from training or competition. However, the coaches continuously suggested that quantity training programmes must be performed with good technique and they felt this was a misunderstood element. This study was a critical step towards gaining a richer and broader understanding on the debate over Quality versus Quantity training from an expert swimming coaches’ perspective which was not currently available in the research literature.

Key words: high-intensity training, high-volume training, long term athlete development, coaching philosophy, mixed methods.

Introduction

Swimming is one of the largest Olympic sports with 32 pool events ranging in distance from 50 to 1500 m. The Gold Medal winning times at the Rio 2016 Olympics ranged in duration from 21.4 s for the 50 m event to 14 min 34.57 s for the 1500 m event. Twenty six out of thirty two (81%) Olympic level swimming events are competed over a race distance of 200 m or less, for typical duration of less than 2 min 20 s. Despite the relatively short distance and duration of the majority of events, swimming coaches are widely acknowledged to place a strong emphasis on high-volume, low-intensity training (HVT) (Lang and Light, 2010).

The relevance of HVT to the physiological requirements of many swimming events is a long standing topic of discussion in the scientific literature (Aspenes and Karlson, 2012). One of the earliest researchers on the topic, David Costill, summarised this by stating “it is difficult to understand how swimming at speeds that are markedly slower than the competitive pace for 3 to 4 hours per day will prepare the swimmer for the supramaximal efforts of competition” (Costill et al., 1991). In the swimming community, this has been referred to as the debate over “Quality vs Quantity” (Maglischo, 2003; Salo and Riewald, 2008). On the quality side of the debate, there is the suggestion that swimmers can reduce training mileage with no loss of endurance capacity if they

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Effects of increased training volume during a ten-day training camp on competitive performance in national level youth swimmers

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ABSTRACT

BACKGROUND: The purpose of this study was to investigate the effects of increased training volume during a 10-day training camp on competitive performance and internal training load (ITL). In addition, coach and swimmer rating of perceived exertion (RPE) for each session was compared.

METHODS: Ten national level swimmers (gender: 4 males and 6 females; age: 15±1 years; height: 170.3±6.4 cm; body mass: 61.4±7.4 kg) participated in the training camp which involved a 36% increase in swimming volume. Competitive performance, as assessed using the FPS (FINA points system), was recorded pre and post-camp. ITL was recorded using the Session-RPE method and REST-Q-22 Sport questionnaire for each session and for day 1, 5 and 10 of the camp, respectively. Coach RPE was recorded after each training session for coach-swimmer RPE comparisons.

RESULTS: Competitive performance increased by 7.1% from pre-camp to post-camp (P<0.001, d=1.6). Session-RPE increased between day 1 and all other days of the training camp (P<0.05), except day 6 (P=0.221). The injury scale of the REST-Q questionnaire increased from day 1 to day 5 (P=0.022). Across 16 swimming sessions, there was a strong correlation between coach and swimmer RPE (r=0.76) however RPE was found to be higher for the swimmers than the coach (P<0.0005) during moderate training sessions.

CONCLUSIONS: These findings suggest that a 36% increase in swimming volume during a 10-day training camp resulted in significant changes to competitive performance and ITL. However, coach and swimmer RPE should be monitored closely during future camps.

(Cite this article as: Nugent FJ, Comyns TM, Warrington GD. Effects of increased training volume during a 10 day training camp on competitive performance in national level youth swimmers. J Sports Med Phys Fitness 2018;58(5):000-000. DOI: 10.23736/S0022-4707.17.07838-0)

KEY WORDS: Physical exertion - Swimming - Athletic performance.

Swimming coaches are widely acknowledged to prescribe large quantities of low intensity aerobic training with the aim of enhancing swimming performance, this is commonly referred to as high volume training (HVT). This training practice is particularly evident at youth level where training volumes of 30 to 60 km per week for 10 to 11 months of the year are common. However, uncertainties exist around the benefits of a period of increased training volume or HVT for youth swimmers as 81% of Olympic level swimming events are competed over a race distance of 200 meters or less, for a typical duration of less than 2 minutes 20 seconds. One of the earliest studies on this topic was by Costill et al. who investigated the effects of a 6 week HVT intervention involving 24 university swimmers. The swimmers were divided into a HVT and control group. The HVT group completed 3 hours of swimming per day while the control group completed 1.5 hours of swimming per day. Following the 6-week intervention, the HVT group experienced a significant reduction in 22.9-meter swimming performance while the control group experienced an increase in 22.9-meter swimming performance. Therefore the HVT group swam slower following the intervention however no further significant differences were found. A recently published systematic review by Nugent et al. identified 2 HVT interventions involving youth swimmers. The 4 and 5 week HVT interventions resulted in no additional improvements in physiological and swimming performance. Therefore
The Effects of Low-Volume, High-Intensity Training on Performance Parameters in Competitive Youth Swimmers

Frank Nugent, Thomas Comyns, Alan Nevill, and Giles D. Warrington

Purpose: To assess the effects of a 7-week low-volume, high-intensity training (HIT) intervention on performance parameters in national-level youth swimmers. Methods: Sixteen swimmers (age: 15.8 [1.0] y, age at peak height velocity: 12.9 [0.6] y, 100-m freestyle 61.4 [4.1] s) were randomly assigned to a HIT group or low-intensity, high-volume training (HVT) group which acted as a control. The HIT group reduced their weekly training volume of zone 1 (low intensity) training by 50% but increased zone 3 (high intensity) training by 200%. The HVT group performed training as normal. Pretest posttest measures of physiological performance (velocity at 2.5- and 4-m blood lactate (velocity2.5mL and velocity4mL) and peak blood lactate), biomechanical performance (stroke rate, stroke length [SL], and stroke index [SI] over a 50- and 400-m freestyle), and swimming performance (50-, 200-, and 400-m freestyle) were assessed. Results: There were no significant 3-way interactions between time, group, and sex for all performance parameters (P > .05). There was a significant 2-way interaction between time and group for velocity2.5mL (P = .02, η2 = .40), SL50 (P = .03, η2 = .37), and SI50 (P = .03, η2 = .39). Velocity2.5mL decreased in the HIT group but increased in the HVT group while SL50 and SI50 decreased in the HVT group. Conclusions: A 7-week HIT intervention was neither beneficial nor detrimental to performance parameters; however, the HIT group completed 6 hours (17.0 km) of swimming per week compared with 12 hours (33.4 km) per week for the HVT group.

Keywords: HIT, HVT, high-volume training, training organization, swimming

Swimming is a cyclical sport with unique physiological and biomechanical demands due to the large variety of racing distances spread across multiple swimming stroke techniques. The gold medal winning times at the 2016 Summer Olympics in Rio de Janeiro ranged from 21.40 s for the 50-m event to 14 min 34.57 s for the 1500-m event. However, 26 out of the 32 (81%) Olympic swimming events are competed over a race distance of 200 m or less, for a typical duration of less than 2 min 20 s. Despite the short duration of the majority of swimming events, the traditional training practices of competitive swimmers typically involve high training volumes (i.e., total training distance or duration) which are, in many cases, well in excess of other cyclical sports such as running, rowing, and cycling. This is particularly evident at the youth level, where training volumes may range from 11 to 20 hours per week spread across 6 to 11 training sessions.

Swimming performance is determined by a number of different physiological and biomechanical parameters. Biomechanical parameters such as stroke rate (SR; number of swimming stroke cycles performed per minute), stroke length (SL; distance the swimmer travels per stroke cycle), and stroke index (SI = SL multiplied by swimming velocity [SV]; an indication of stroke efficiency) are among the best determinants of swimming performance. This is perhaps one of the incentives for undertaking high training volumes, as swimming coaches suggest that large amounts of practice, typically around 11 to 20 hours per week, are required to develop efficient stroke mechanics. In recent years, a number of studies have investigated the effects of a low-volume, high-intensity training (HIT) program versus a low-intensity, high-volume training (HVT) program on swimming performance.

A HIT program is defined as a lower volume program which focuses on performing intervals of HIT (zone 3, >4-m blood lactate) to improve performance. An HVT program is defined as a higher volume program which focuses on performing prolonged low-intensity training (zone 1, <2-m blood lactate) to improve performance. A number of high-profile international swimmers have had success using HIT programs, in contrast to more traditional HVT programs, which has led to debate within the swimming community. Anecdotal evidence suggests that many of the best swimming coaches and athletes are advocates of HIT, hence the controversy.

A recent systematic review by Nugent et al investigated the effects of a HIT intervention on performance in competitive swimmers. Seven studies met the inclusion criteria, ranging in duration from 4 weeks to 4 years, and were conducted on youth, university, masters, and elite swimmers. Six out of the 7 studies found that HIT resulted in improvements to performance measures such as maximal rate of oxygen consumption and swim velocity at fixed blood lactate values. Four of the 7 studies found that HIT resulted in improvements to performance in events from 50 to 2000 m, while none of the 7 studies resulted in a reduction in performance. The review concluded that the applications of HIT may be limited, as a number of the controlled studies were only 4 to 5 weeks in duration; therefore, more research is required.

To the best of the authors’ knowledge, the effects of HIT on biomechanical parameters in competitive swimmers have not been investigated. Swimming coaches have suggested that HIT programs may be detrimental to technical development, as swimming technique is best practiced at low intensities; this topic warrants further investigation. In addition, none of the previous HIT studies have accurately quantified the training completed by the HIT and HVT groups using measures such as heart rate, blood lactate, rating of perceived exertion, etc. This is important during swimming...
Effects of Low Volume, High-Intensity Training on Performance in Competitive Swimmers: A Systematic Review

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Background
Swimming coaches are widely acknowledged to place a strong emphasis on developing a swimmer’s aerobic capacity through the use of low intensity, high volume training (HVT) (1). The relevance of HVT to the physiological requirements of many swimming events has long been questioned in the scientific literature (1, 2) as 81% of Olympic level events are completed over 200 meters or less, for a typical duration of less than 2 minutes 20 seconds.

HVT has been linked to an increased risk of shoulder injury (3), overtraining syndrome (4) and early specialisation (5) in competitive swimmers. A reduction in training volume through implementing a low volume, high-intensity training (HIT) intervention could potentially have many beneficial effects on the overall health and longevity of competitive swimmers. A detailed review of the research involving HIT interventions in competitive swimmers is currently lacking.

Aim
The aim of this systematic review was to examine the extent and quality of the current research literature in order to determine the effects of HIT on physiological performance and swimming performance in competitive swimmers.

Physiological Performance

Swimming Performance

VDpeak
VDprompt
LACaerobic
LACprompt

Time trial performance
Competitive performance

Methods
This methodology followed the PRISMA protocol (6). A search of relevant databases, conference proceedings, reference lists and contacts with prominent authors was performed until December 2015. Studies were eligible for review if they met the following inclusion criteria:

• Competitive swimmers
• ≥4 weeks HIT intervention
• Comparison group had to involve a higher training volume
• Outcome measures of physiological and swimming performance (Figure 1)
• All experimental study designs
• Quality assessment of the eligible studies was performed using the Quality Index checklist (7).

Results
• Seven studies were found to be eligible for review. The 7 studies consisted of a wide range of competitive swimmers and included youth swimmers (8, 9), elite swimmers (9,10), university swimmers (11, 12, 13) and master swimmers (14).
  
• Three of the studies were randomized controlled studies (8, 9, 10) and 4 were non-randomized controlled studies (11, 12, 13, 14), which included a 1 year and 4 year longitudinal intervention.
  
• The Quality Index score of the 7 studies had a mean of 16.1 points (range 7 to 22) out of a maximum of 22 possible points.
  
• Six out of the 7 studies found that HIT intervention resulted in significant improvements in physiological performance, both aerobic (8, 9, 11, 12, 13, 14) and anaerobic (9, 13).
  
• Four of the 7 studies found that HIT resulted in significant improvements in swimming performance in events from 50 to 2000 m (9, 12, 13, 14).

Conclusions
• Current evidence suggests that a ≥4 to ≥8 week HIT intervention performed in combination with a 40–55% decrease in training volume can either improve or maintain performance in competitive swimmers competing in events from 50 to 2000 m.

• Future research should involve controlled HIT studies at ≥8 weeks using outcome measures of physiological, biochemical and swimming performance.

References

Acknowledgments
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Strength and Conditioning Considerations for Youth Swimmers

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ABSTRACT

YOUTH SWIMMERS, AGED 7–13 YEARS, ARE AN ATHLETIC POPULATION THAT CAN BENEFIT FROM A STRENGTH AND CONDITIONING (S&C) PROGRAM WHICH CATERS FOR THEIR DEVELOPMENTAL AND SPORTS-SPECIFIC NEEDS. THIS ARTICLE PROVIDES CONSIDERATIONS FOR S&C PROGRAMS FOR YOUTH SWIMMERS. PRACTICAL EXAMPLES OF EXERCISES, MOVEMENT SCREENS, AND PROGRAMS ARE PROVIDED.

INTRODUCTION

Swimming is one of the largest Olympic sports with 35 pool events and 2 open water events. Pool events range in distance from 50 to 1,500 m, whereas open water events are competed over a distance of 10 km. The demands of swimming are unique because of the large variety of racing distances spread across multiple swimming stroke techniques—freestyle, backstroke, butterfly, and breaststroke. Most swimming races can be broken down into 3 components—the start, the turn(s), and the swim itself with each component having specific technical requirements depending on the individual stroke technique. The variety of race distances, stroke events, and race components makes swimming a complex and demanding sport from a physical, technical, and tactical standpoint.

Swimming is widely known as a sport that demands a high level of training commitment from a young age. It is common practice for youth swimmers to complete 6–8 sessions, or 11–15 hours of training per week for an entire season (21). Consequently, youth swimmers are an athlete population that has been found to be at greater risk of early specialization, where a bias is placed toward intensive year round training in 1 sport at the expense of a more global movement skill development across a range of sports (18). The risks surrounding early specialization in youth athletes are heavily debated in the literature with a greater incidence of psychological burnout, injury, and early dropout evident in sports that tend to specialize from an early age (17–19). An age-appropriate strength and conditioning (S&C) program has been suggested as a valuable tool in helping to decrease likelihood of injury while providing opportunities to develop a wide and varied array of movement skills which are seen as vital to long-term engagement in physical activity and sport (8,16).

In addition to developing a wide variety of movement skills, S&C programs for youth swimmers should aim to lay long-term foundations for enhancing performance in sports-specific skills. Swimming performance depends on a balance between the propulsive power generated by the arm and leg actions during the swimming stroke and the resistance created by the drag, or water resistance, encountered by the body during swimming (23). A swimmer will reach his/her maximum velocity when he/she fails to produce propulsive power that exceeds the resistance acting on him/her (3). Therefore, S&C programs for swimmers should aim to increase propulsion through the water by enhancing muscular force and power production while at the same time decreasing resistance through the water by improving body position (23). Optimizing the moments, a swimmer has access to ground reaction forces (GRFs) during a race, namely the start (0–15 m) and the turn(s) (5–10 m), is also an area that has potential to enhance swimming performance (4,5,24).

KEY WORDS:
fundamental movement skills; long-term athlete development