The health & wellbeing benefits of swimming

individually
societally
economically
nationally

Commissioned by Swim England's Swimming and Health Commission, chaired by Professor Ian Cumming

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This report was produced by the Swimming and Health Commission. The Commission was established by Swim England to identify evidence for the health benefits of swimming and to promote future research in this area. Although established by Swim England, the Commission operates entirely independently under the chairmanship of Professor Ian Cumming.

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Foreword

Whether it's for leisure, pleasure or competition, swimming is a great way to improve your health and wellbeing. These are the key themes from a scientific report commissioned by Swim England on the health and wellbeing benefits of swimming. The evidence from this report is an important landmark and shows that:

- Swimming is one of England's most popular sports
- Swimming may be associated with a decrease in early death due to cardiovascular disease and any other cause
- Swimming can have a number of health and wellbeing benefits for individuals, patients, communities, the public and the nation
- There is emerging scientific data for the physical and mental health benefits of swimming
- Research on swimming and health benefits is sparse and sporadic. Specific areas of further research need to be developed
- The future now offers opportunities for Swim England to lead on a strategy that engages with and retains the public passion for swimming for health and wellbeing

Going forward, it will be important to link the health, economic and wellbeing benefits of swimming as a key strategy to address the physical inactivity epidemic in this country. We also need further research on the specific health and wellbeing benefits of swimming.

This is not the time to tread water; we need to enrich and harness the evidence and opportunity, and to encourage more to swim, and swim regularly. We need to move as a nation to take more exercise. So do swim for pleasure, leisure, or as a sport.

Professor Dame Sally C. Davies
Chief Medical Officer for England

Introduction

Swim England's 'Swimming and Health Commission' is the first time that the relationship between swimming and health and wellbeing has been scientifically investigated in this depth. Swim England is the national governing body for the sport in England and they commissioned this work to provide a baseline of knowledge from which to build future evidence and share best practice.

An independent team of United Kingdom (UK) researchers have reviewed and scrutinsed the available evidence for the Commission on the benefits of swimming for: individuals, patients, communities and nations. Their scope was to scientifically review the health and wellbeing benefits across the lifespan, to highlight disparities in evidence, practice and access, and to evidence the many health advantages that swimming regularly affords to us all.

It is clear from the evidence that being able to swim, swimming regularly, and swimming as a part of daily community life can have considerable health and wellbeing benefits. For instance, research has identified that any amount of swimming participation compared to those who engaged in none, was associated with a 28% and 41% reduction in all cause and cardiovascular disease cause mortality respectively. The striking evidence of where swimming has afforded significantly improved health, quality of life and a sense of community are additional examples of best practice that need to be promoted across the nation.

And it is evident that water-based exercise can confer several specific advantages, as compared to land-based exercise. For this reason, water-based exercise prescription should be a key consideration for all health care clinicians, providers and commissioners.

It is also emphasised that having adequate opportunities to learn to swim and have positive experiences in early life, particularly among those from disadvantaged backgrounds, may be an important step to tackle drowning as one of the causes of avoidable and tragic death.

It is estimated that those who swim for recreational or competitive purposes are eight times more likely to meet physical activity guidelines. Long-term swim training can also improve cardiorespiratory fitness or endurance in healthy pre-pubertal girls and adults, women during pregnancy, children with asthma, and adults with osteoarthritis (a condition affecting joints, causing pain and stiffness).

It is however concerning to find in many areas a profound lack of robust scientific evidence in swimming as a contemporary means to: increase physical activity levels, move the inactive into swimming as a preferred physical activity, and to use a variety of community swimming venues to promote health and wellbeing at population levels.

This report is just the start of a focus on swimming being a greater part of the national and international picture to increase health and wellbeing through physical activity, leisure and water based sports.

This full scientific report of the commission is divided into seven chapters. Each chapter contains a review of the evidence for the health benefits of swimming together with key points and summary statements. Chapter one focuses on the individual health benefits of swimming and other water based activities. Swimming and mental health and wellbeing is covered in chapter two. The physiology of swimming and health benefits is detailed in chapter three. Chapter four explores the evidence for swimming benefits for communities within a framework of delivering community capacity. Chapter five details the public health benefits of swimming and the importance of fulfilling key societal priorities such as reducing the number of deaths by drowning. Chapter six describes the benefits of swimming as a sport and the final chapter seven looks at the economic case for swimming. A summary of this full report is available as a separate document and highlights the key points from each chapter.

Glossary and definitions

Swim England is the national governing body for swimming in England. The organisation and network helps people learn how to swim, enjoy the water safely, and compete in all their sports.

Swimming is the sport or activity of propelling oneself through water using the limbs. In the context of this summary it includes all forms of swimming and water based activities.

Physical Activity (PA) is any volitional movement of skeletal muscle that results in energy expenditure is regarded as physical activity.

Exercise is a form of leisure-time physical activity that is planned, structured, and repetitive. Exercise training is purposeful and is performed with specific external goals, including the improvement or maintenance of physical fitness, physical performance or health.

Sport is a form of physical activity that includes rules and is usually competitive.

Metabolic Equivalents (MET). Physical activity is measured in METs e.g. the energy it takes to sit quietly. For the average adult, this is about one calorie per kilogram of body weight per hour. Moderate intensity activity is those that used 3 – 6 METS and vigorous activities more than 6 METs.

Chapter 1

The individual physical health benefits of swimming: a literature review

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Key words:

swimming
swimming pool
aquatic therapy
hydrotherapy

Introduction

The global pandemic of physical inactivity is well recognised with concomitant implications for global health (Andersen et al., 2016). In the United Kingdom (UK), a significant proportion of children, adolescents and adults fail to meet the national recommendations for physical activity: 90% of 2-4 year olds, 80% of 5-15 year olds (BHF, 2015), and 39% of adults (BHF, 2017). Similar patterns are seen globally (Hallal et al., 2012). The cost of such physical inactivity is high – globally, the economic burden of physical inactivity in terms of healthcare costs, productivity losses and disability adjusted life years amounts to £51.5 billion per annum (Ding et al., 2016).

An intimate relationship exists between physical (in)activity and physical health (Reiner et al., 2013). Sedentary behaviour is associated with adverse cardiometabolic adaptations such as insulin resistance, altered lipid trafficking, muscle fibre type alteration and ectopic fat storage (Saunders et al., 2014). Poor cardiorespiratory fitness/physical inactivity is a significant risk factor for the majority of non-communicable diseases (NCDs), including cardiovascular disease, dementia, certain cancers, osteoporosis, obesity and Type 2 diabetes (Lee et al., 2012; Reiner et al., 2013). It is also the strongest independent risk factor for development of post-operative morbidity and mortality (Snowden et al., 2013).

A multi-agential approach to promoting physical activity has been highlighted as imperative to the promotion of national and international physical activity (PA) guidelines (Gates et al., 2016). These guidelines detail the recommended amount of physical activity required to achieve physical health benefits for young children (at least 180 minutes per day), children aged 5 and over (at least 60 minutes per day), and adults (at least 150 minutes of moderate intensity activity per week, plus two episodes of strength/balance training)(Department of Health, 2011). Physical activity may be multi-modal, including activities such as walking, jogging/running, aerobics, racket sports, swimming, cycling. Adults who are physically active have a reduction in all-cause mortality of up to 30% compared to sedentary individuals and a reduced risk of developing chronic disease (Kokkinos, 2012). Furthermore, evidence suggests that physical activity and exercise interventions produce similar results to drug therapy in terms of mortality outcomes in the secondary prevention of coronary heart disease, rehabilitation post-stroke, treatment of heart failure and prevention of diabetes (Naci and Ioannidis, 2013).

This chapter presents a contemporary review of the empirical evidence in relation to swimming and aquatic exercise, and physical health. Specifically, it will aim to elucidate how swimming/aquatic exercise influences the physical health of the general population and, additionally, certain specific sub-groups or those with chronic disease.

Why might swimming influence physical health?

Most studies exploring the relationship between physical activity and physical health have used interventions such as walking, cycling, running or aerobics classes (Chase et al., 2008a; Mohr et al., 2014). Of interest are the unique features that aquatic based exercise offers, and how swimming and aquatic exercise relate to health outcomes. Swimming and other forms of aquatic exercise (aqua-jogging and aqua-aerobics for example) are some of the most popular choices for meeting physical activity recommendations – both for the aerobic and strength/balance element (Lazar et al., 2013). Exercise in an aquatic environment confers many benefits – minimised weight-bearing stress, a humid environment and a decreased heat load (Yuan et al., 2016). This may offer a personalised exercise opportunity for particular populations, especially the elderly, pregnant women, and those with arthritis, type 2 diabetes, disabilities or excess adiposity (Delevatti et al., 2015; Lazar et al., 2013). The unique nature of swimming and aquatic exercise will be considered.

The aquatic environment has been recognised as a place for active play and recreational exercise since the nineteenth century (Wiltse, 2013). Chase et al. (2008) compared the health aspects of swimming with alternative forms of aerobic exercise, and sedentary behaviour. Participants included 10,518 women and 35,185 men aged 20-88 years old; the majority were Caucasian and of middle/upper socio-economic status. Screening included a formal subjective and objective history, anthropometric measurements, blood tests and a graded exercise test. Participants were categorised as 'sedentary' (no participation in activity over the previous three months), 'walkers' (primarily engaged in run/walk/jog at a pace ≥15min/mile), 'runners' (primarily engaged in run/walk/jog at a pace ≤15min/mile), and 'swimmers' (exclusively engaged in swimming activity). The results demonstrated that all types of physical activity produced demonstrable health benefits in comparison to a sedentary lifestyle. Of all the groups, swimming and running achieved the highest treadmill test duration/maximal metabolic equivalent (MET) levels, although the Body Mass Index (BMI) of swimmers was significantly higher than that of runners. It is worthy of note however, that the 'swimmers' category only formed approximately 1% of the total participant population, and therefore this could affect the internal validity of the study. Equally, the limited demographics of the population could adversely affect external validity. The authors, however, conclude that swimming constitutes a valuable lifetime activity that appears to produce healthy levels of cardiorespiratory fitness and, as such, is a viable alternative to other forms of exercise. This is further supported by the results of a prospective study of the health effects of physical activity and fitness in men (n=40,547), that concluded that swimmers had lower mortality rates than those who were sedentary, walkers or runners even after controlling for age, body mass index, smoking/alcohol and family history (Chase et al., 2008b). Similar results have been demonstrated by Oja et al. (2015); in a cohort study of over 80,000 British adults, swimming participation was associated with a significantly reduced risk of all-cause mortality of 28%, and cardiovascular disease mortality of 41%.

Clearly, the aquatic environment offers scope for aerobic activity, however the specific interaction between physiological and hydrodynamic effects of immersion are also of particular interest and are thought to confer additional effects/advantages (Chase et al., 2008b); Becker (2009) describes these in detail (Table 1).

Table 1:
Hydrodynamic principles of water immersion (after Becker, 2009 and Brody and Geigle, 2009)

Hydrodynamic principle	Effect
Density	The human body density is slightly less than that of water, therefore the volume of water displaced weighs more than the immersed body resulting in an upward force equal to the volume of water displaced
Hydrostatic Pressure	Pressure is proportional to the liquid density and the immersion depth. Hydrostatic pressure results in plastic deformation of the body, shifting blood towards the heart, raising right atrial pressure, and causing a cephalad displacement of the diaphragm
Buoyancy	Immersion to the xyphoid offloads bodyweight by 60% or more, to C7 by 75% or more. Buoyancy results in 'offloading' of peripheral and spinal joints
Viscosity	Limb movement in water is subject to drag force and turbulence. Viscous resistance offers opportunities for strength training via the principle of loading
Thermodynamics	Water may be used over a wide range of temperatures due to its heat capacity and conduction properties. Many public pools operate at 27-29°C, although sometimes increase to 33.5-35.5°C for 'therapeutic' sessions. Neutral temperatures provide a safe and comfortable environment for exercise

In total, the effects of swimming and aquatic exercise on physical health are sequelae of both aerobic training, and the unique properties of water as an exercise medium. The following sections will consider the evidence to support these beneficial health effects, from a body system perspective.

Effects of swimming on cardiovascular and cardiometabolic health

Displacement of blood into the thoracic vasculature (secondary to the hydrostatic pressure gradient) results in increased venous return, a 60% increase in central blood volume, increased cardiac preload, a concomitant increase in stroke volume of approximately 35%, and a reduction in heart rate secondary to baroreceptor stimulation (Becker, 2009; Brody and Geigle, 2009; Lazar et al., 2013; Weston et al., 1987). Immersion to the neck also reduces systemic vascular resistance via a reduction in sympathetic vasoconstriction and nitric oxide release; this state continues into the post-immersion period (Becker, 2009; Lazar et al., 2013). Whilst systolic pressure increases with physical activity, this is generally less than on land; end-diastolic pressures are decreased (Becker, 2009).

Upon commencement of aerobic exercise (specifically aqua-jogging), oxygen consumption is noted to be greater for a given speed of ambulation, therefore a beneficial training effect may be realised at a slower speed than on land (Evans et al., 1978). Lazar et al. (2013) note that, given the viscous resistance of water, the energy cost of swimming a given distance is approximately four times that of running the same distance. Whilst it has been long suggested that swimming is associated with a lower maximal oxygen consumption(VO_2max) than other aerobic exercise (Holmér and Astrand, 1972), data are in fact equivocal; Lazar et al. (2013) suggest that these differences are attributable to factors such as swim skill/speed, clothing, water temperature, and baseline cardiac status.

1. Swimming/aquatic exercise and risk factor modification

Aerobic exercise is recommended as a cardioprotective lifestyle intervention, reducing cardiovascular mortality in both genders and across the life span (Nagle et al., 2017). However, the effect of swimming on blood pressure modification has produced inconsistent results (Lazar et al., 2013). In normotensive subjects, swim training has been associated with a small rise in systolic and diastolic blood pressure (Chen et al., 2010; Cox et al., 2006). It should be noted however, that this rise was not clinically significant as it did not take participants into the hypertensive category (Lazar et al., 2013). Conversely, in male and female subjects, with varying severities of hypertension, swimming has been consistently associated with a reduction in blood pressure and improvements in vascular function such as carotid artery compliance, flow-mediated dilatation and cardiovagal baroreflex sensitivity (Arca et al., 2014; Bartels et al., 2016; Chen et al., 2010; Laurent et al., 2009; Mohr et al., 2014; Nualnim et al., 2012; Tanaka, 2009). Swim/aquatic exercise training at moderate to high intensity, may confer greater anti-hypertensive benefits, however further research is warranted (Mohr et al., 2014; Nagle et al., 2017).

Obesity is a major public health concern and associated with significant cardiovascular and cardiometabolic co-morbidity (Boidin et al., 2015). Between 1971 and 2002, obesity increased three-fold amongst children and two-fold amongst adults, with significant disparities in ethnic groups (Stempski et al., 2015). As forms of aerobic activity, swimming and aquatic exercise are legitimate choices for weight reduction and management (Lazar et al., 2013). Aerobic activity is associated with decreased body fat, attenuation of loss of lean body mass commonly seen during dietary restriction, and reduction of visceral adipose tissue (Klijn et al., 2007). For obese individuals, the unique nature of the aquatic environment, specifically the ability to reduce weight-bearing and thermoregulatory stressors, may confer an added advantage relative to other forms of aerobic exercise. Studies regarding the effects of swimming and aquatic exercise on body composition have, however, been variable (Lazar et al., 2013; Meredith-Jones et al., 2011). Some researchers have shown no significant changes in body weight, percentage body fat or fat distribution with swimming or aquatic exercise programmes (Gwinup, 1987; Tanaka et al., 1997). Others have demonstrated significant improvements in the same parameters in healthy and Type 1 diabetic young women (Sideraviciūte et al., 2006), sedentary older women (Cox et al., 2010), obese adults (Boidin et al., 2015), Type 2 diabetic men (Cugusi et al., 2015), adults with coronary artery disease (Volaklis et al., 2007), and post-menopausal women (Colado et al., 2009). The confounding factors underpinning conflicting results may be attributed in part to discrepancies in: programme type, intensity and duration; addition of caloric/dietary restriction; or differences in baseline parameters (Meredith-Jones et al., 2011).

Interest has been expressed in the effects that swim training and aquatic exercise may have on blood lipids, glycaemia, and insulin sensitivity, known aetiological factors in the genesis of cardiometabolic morbidity (Lazar et al., 2013; Meredith-Jones et al., 2011). The augmented atrial pressures associated with immersion are known to cause neural and hormonal adjustments, including suppression of the renin-angiotensin-aldosterone system (RAAS) (Lazar et al., 2013). Activation of the RAAS has been associated with development of conditions such as obesity and Type 2 diabetes (Delevatti et al., 2015). A recent systematic review sought to better elucidate the relationship between aquatic exercise and glycaemic and lipid profile variables (Delevatti et al., 2015). Eight studies considered the effects of prolonged aerobic training (8-24 weeks), with variable exercise protocols and session duration/frequency. Participants included both sexes, a range of age groups, and individuals with coronary artery disease, chronic heart failure, Type 2 diabetes and dyslipidaemia. All studies demonstrated improvement in at least one variable when compared to the control group or pre-training measurements. Only one study compared aquatic exercise to land-based exercise, however, the biochemical improvements seen in both were not significantly different. The authors conclude that, despite methodological limitations, there is some evidence to indicate that aquatic exercise constitutes an interesting therapeutic option for improving lipid profile and glycaemic control.

2. Swimming/aquatic exercise and heart disease

The use of swimming and aquatic therapy for individuals with established cardiovascular disease has long been debated, with concerns expressed that immersion-related central haemodynamic responses may be detrimental in this population causing myocardial ischaemia, arrhythmia or ventricular decompensation (Adsett et al., 2015; Lazar et al., 2013; Meyer, 2006). However, swimming and aquatic exercise are increasingly used as a successful form of cardiac rehabilitation in both coronary artery disease and congestive heart failure (Adsett et al., 2015; Becker, 2009; Laurent et al., 2009; Lazar et al., 2013; Neto et al., 2015). In a review of relevant literature, Lazar et al. (2013) note that swimming has been associated with delayed sensation of angina compared to land-based exercise. Consequently, the Association of Chartered Physiotherapists in Cardiac Rehabilitation offers the following advice to patients with known coronary heart disease: *"Due to the buoyancy and temperature in water it is very easy to underestimate how hard your body is working. It is a good idea to exercise at a lower level than you would do out of the water. You should always feel comfortable and able to continue easily with the activity"* (ACPICR, undated). An increasing volume of literature supports the use of swimming and aquatic exercise in patients with impaired left ventricular ejection fractions (LVEF), but stable symptoms (Adsett et al., 2015; Lazar et al., 2013; Neto et al., 2015). Benefits included improvements in LVEF/ 6 Minute Walk Test / VO_2peak and increased levels of plasma nitrates (Adsett et al., 2015; Laurent et al., 2009; Neto et al., 2015; Teffaha et al., 2011). Becker (2009) has proposed a clinical algorithm for aquatic activity decision-making, intended to guide healthcare practitioners in advising patients safely and appropriately.

In summary, evidence suggests that swimming and aquatic exercise are viable methods for improving cardiorespiratory fitness, and may be a particularly attractive option for those individuals who are less tolerant of land-based exercise. Furthermore, swimming appears to constitute a valuable intervention for risk factor modification, especially for hypertension. Swimming and aquatic exercise appear to be safe in individuals with established cardiovascular disease, where symptoms are stable, and exercise prescription is directed by an appropriately qualified practitioner.

Effects of swimming on pulmonary health

Deep water immersion (to at least the level of the thorax), has significant implications for the pulmonary system. This is in part mediated by translocation of blood to the thoracic vasculature and also by the direct compression of the chest wall by hydrostatic pressure (Becker, 2009). The resultant impact - 6-9% reduction in vital capacity and an increase in work of breathing – means that the aquatic environment can plausibly offer a valuable opportunity for respiratory training (especially inspiratory muscle training) and rehabilitation. Santos et al. (2012) conducted an observational study of healthy seven to eight year old boys who either played football twice a week (n=25), swam twice a week (n=25), or were sedentary (n=25). The swim group showed statistically significantly higher levels of maximal inspiratory and expiratory pressures (indicative of greater respiratory muscle strength) compared to both football and sedentary groups. Similarly, favourable advantages in spirometry have been demonstrated in adult swimmers compared to individuals who played other sports (Mehrotra et al., 1998). Further research suggests that these advantages become more significant the longer the individual sustains swimming as a form of regular physical activity (Nilesh et al., 2012). Santos et al. (2012) conclude that, theoretically, swimming could be recommended in chronic respiratory disease, or other degenerative conditions, where respiratory muscle strength needs to be maintained or gained.

Of particular interest is the effect of swimming interventions for children with asthma. Asthma is the most common chronic disease in the paediatric population, and is increasing in prevalence in many parts of the world (Wang and Hung, 2009; Wong and Chow, 2008). A cycle of deconditioning and poor cardiorespiratory fitness is known to occur in many children, as fear of an asthma attack can preclude engagement in physical activity (Welsh et al., 2005). Consequently, swimming is commonly recommended as a form of physical activity for this population given that the environment offers humidity, warmth, low pollen exposure and hydrostatic pressure against the chest wall which reduces the work of breathing associated with expiration (Beggs et al., 2013). Furthermore, swimming has the additional advantages of promoting normal physical/psychological development, developing cardiorespiratory fitness and enhancing lung volumes and breathing techniques (Wang and Hung, 2009). A Cochrane review aimed to determine the effectiveness and safety of swimming as an intervention in children and adolescents with asthma

(Beggs et al., 2013). Based on eight studies (n=262), the authors concluded that there was moderate level evidence that swimming increased lung function, and high level evidence that it increased cardiorespiratory fitness. There were no reported adverse effects on asthma control or exacerbation. The quality of evidence regarding swimming and aquatic exercise for adults with asthma is very low, such that a recent Cochrane review was unable to make recommendations regarding effectiveness and safety (Grande et al., 2014).

Swimming-pool based exercise has also been used as a form of pulmonary rehabilitation for individuals with chronic obstructive pulmonary disease (COPD) (de Souto Araujo et al., 2012; Rae and White, 2009). Pulmonary rehabilitation is a key component of COPD therapeutic management, and is particularly effective in improving exercise capacity and quality of life (McCarthy et al., 2015). A Cochrane Review sought to compare the effectiveness and safety of water-based exercise in patients with COPD, as compared to no exercise or land-based exercise (McNamara et al., 2013a). Five studies were included (n=176), with exercise based interventions lasting between four and twelve weeks. The included studies provided limited quality evidence that water-based training offered advantages over land-based training in terms of improving exercise endurance. Little information was available in terms of long term effects of training. A randomised controlled trial of water-based training versus land-based training or control for patients with COPD and co-existent co-morbidities such as obesity, or musculoskeletal/neurological conditions was conducted (McNamara et al., 2013b). Results of this study showed that water-based training was significantly more effective than either land-based training or control for improving exercise capacity (peak and endurance), and fatigue (as measured by the Chronic Respiratory Disease Questionnaire). Given that water-based training confers at least equivalent benefits as land-based programmes, aquatic pulmonary rehabilitation should be considered. This may be of particular importance for individuals with other physical co-morbidities who are better able to exercise (and progress exercise) in water (McNamara et al., 2015)

In summary, evidence suggests that swimming and aquatic exercise can influence respiratory muscle strength and pulmonary function in healthy children and adults. Water-based exercise is also a viable therapeutic option for improving lung function and cardiorespiratory fitness in certain lung pathologies such as asthma and COPD.

Effects of swimming on musculoskeletal (MSK) health

During immersion, the increased cardiac output is preferentially distributed to the skin and muscle rather than the splanchnic beds, resulting in a 225% increase in muscle blood flow and, potentially, an increase in oxygen delivery to active muscle (Becker, 2009). The effect of buoyancy on the musculoskeletal system is also significant, mitigating ground reaction forces, thereby reducing compressive weight-bearing stresses on joints (Barker et al., 2014). The relative ease of movement in water may also activate supraspinal pathways resulting in a reduction in perceived pain (Hall et al., 2008). Furthermore, immersion in thermoneutral water attenuates the sympathetic nervous system response which, combined with the effects of hydrostatic pressure, may serve to reduce oedema and pain perception in individuals with musculoskeletal (MSK) complaints (Barker et al., 2014).

The Global Burden of Disease Study 2010 demonstrated that MSK conditions are highly prevalent, responsible for 21.3% of total years lived with disability globally, and constitute the fourth greatest burden for global health (Hoy et al., 2015). Given that this burden is predicted to rise as a result of the projected increases in the ageing population, effective MSK management strategies are a critical concern for public health, and the beneficial effects of swimming and aquatic exercise have been lauded as viable therapeutic options (Barker et al., 2014). A meta-analysis of 26 randomised and quasi-randomised trials investigating the effects of aquatic exercise on MSK conditions concluded that, when compared with no exercise controls, aquatic exercise achieved moderate improvements in physical function, pain and quality of life (Barker et al., 2014). When compared with land-based exercise, aquatic exercise achieved comparable results. The authors conclude that these findings support the notion that patients can choose the mode of intervention that is most appealing, therefore promoting compliance and adherence. Whilst this study investigated MSK conditions *en masse*, systematic reviews and randomised controlled trials of individual conditions have produced similar findings, for example in osteoarthritis (OA) (Bartels et al., 2016; Batterham et al., 2011; Lu et al., 2015; Waller et al., 2014), ankylosing spondylitis (Dundar et al., 2014) and fibromyalgia (Lima et al., 2013). Whilst the benefits of regular exercise in improving functional independence and quality of life for individuals with rheumatoid arthritis have been acknowledged, there remains concern regarding exercise prescription for those with significant damage, especially in weight-bearing joints (Finckh et al., 2003). As such, it is proposed that exercise programmes should be designed around modailities that reduce joint loading, particularly water walking and swimming (Finckh et al., 2003).

One study explored the effects of swimming on OA (Alkatan et al., 2016). In this study, 48 adults with OA were randomly assigned to twelve weeks of supervised swim or cycle training. The results indicated that swimming elicited similar if not enhanced effects on vascular function and inflammatory markers compared to cycle training. Whilst clearly significant in terms of improving cardiovascular disease risk profile, the reduction in inflammatory markers is also highly relevant in terms of OA pathogenesis and progression.

In summary, evidence suggests that aquatic exercise has positive effects for a wide range of musculoskeletal conditions, favourably influencing pain, function and, for some, quality of life. The nature of the aquatic environment is ideally suited to individuals with MSK problems, given the reduced compressive joint force secondary to buoyancy. Further high quality evidence is needed to establish optimal physical activity and exercise programmes.

Effects of swimming on neurological health

It is well recognised that exposing infants to physical exercise facilitates neurological development and subsequent motor abilities (Sigmundsson and Hopkins, 2010). A number of small preliminary studies have suggested potential improvements in motor development as a result of baby swimming (specifically prehension and balance), however the methodological limitations preclude definitive conclusions (Dias et al., 2013; Sigmundsson and Hopkins, 2010).

In adults with neurological disease, water based physical activity has been more widely explored (Marinho-Buzelli et al., 2015; Plecash and Leavitt, 2014). A systematic review aimed to investigate the effects of swimming/aquatic exercise on the mobility of individuals with neurological disease. Twenty studies were considered, with participants including individuals with multiple sclerosis (MS), Parkinson's disease (PD) and stroke, predominantly in the chronic phase of their disease. Dynamic balance and walking performance were the most frequently measured outcomes. The authors conclude that there is moderate level evidence that aquatic exercise improves mobility in individuals with neurological disorders, but acknowledge that heterogeneity was high. There was a lack of high level evidence that water based exercise was superior to land-based interventions.

A randomised single-blind controlled pilot study (not included in the systematic review) endeavoured to compare the effects of aquatic exercise versus land-based exercise on balance in individuals with PD (Volpe et al., 2014). Thirty-four PD patients were randomised to either aquatic exercise or control (usual land-based rehabilitation). All participants underwent the same rehabilitation period. No adverse effects were reported and compliance was good amongst both groups. Both groups demonstrated improvements post-intervention, but between group analysis revealed that the aquatic exercise group made significantly greater improvements in the domains for Berg Balance, Activities-Specific Balance Confidence, Falls, Falls Efficacy and PD-Questionnaire-39. The authors note that the unique physical properties of water appeared to play a critical role in ameliorating balance control, offering enhanced proprioceptive training and protected conditions in which to activate postural reactions thereby reducing the likelihood or fear of falling.

For patients with MS, fatigue is one of the most common and disabling symptoms with far reaching biopsychosocial sequelae (Wood et al., 2013). Exercise is considered a significant component of MS management, with implications for slowing disease progression (Kargarfard et al., 2012). A randomised controlled trial of 32 women with relapsing-remitting MS aimed to explore the impact of aquatic therapy on MS-related fatigue (Kargarfard et al., 2012). Participants were randomly allocated to either aquatic training for eight weeks or control (maintenance of normal daily activity). Using the Modified Fatigue Impact Scale, the authors revealed that individuals who had received aquatic training showed significant improvements in comparison to the control group. Furthermore, these findings were more significant at eight weeks than at four. The authors hypothesise that the thermodynamic properties of water permitted individuals with MS to exercise without experiencing heat-fatigue, and the effects of buoyancy allowed greater periods of physical activity to be endured before tiring. No adverse events were reported within the aquatic training group, but attrition was high from both control (n=5) and intervention groups (n=6), limiting the internal validity of the study.

In summary, evidence suggests that exercise in an aquatic environment offers additional advantages for individuals with neurological and neurodegenerative conditions. In particular, exercise in water promotes balance and confers a greater margin of therapeutic safety for individuals with an elevated risk of falling (Becker, 2009). Given the prevalence of baby swimming classes, future research should aim to establish the benefits for neurological development.

Effects of swimming on health for people with disability

It is well recognised that people with disability are less physically active than those without (Li et al., 2016; Sport England, 2015), and yet greater participation has been associated with better physical and psychological health (Martin Ginis et al., 2017). Physical activity programmes are required that address environmental barriers and offer appropriate resources (Fragala-Pinkham et al., 2010; Mulligan and Polkinghorne, 2013). Other barriers, from the perspective of adolescents with cerebral palsy (CP), are that physical activity is associated with fatigue, pain, risk of injury and is not fun to engage with (Declerck et al., 2016). Paediatric aquatic therapy has been well described in the literature (especially for children with CP), as it enables individuals to perform activities that they could not achieve on land (Lai et al., 2015). In particular, the aquatic environment increases postural support, provides greater protection to joint integrity and improves muscle strength, cardiorespiratory fitness and gross motor function (Kelly and Darrah, 2005; Lai et al., 2015).

Kelly and Darrah (2005) notes that many studies of aquatic therapy in children with disability have described individualised interventions. There is, however, increasing interest in group aquatic exercise schemes, as a way of providing physical activity opportunities in a motivating and socially stimulating environment. Kelly and Darrah (2005) suggest that this may facilitate greater engagement and compliance. One study has described a ten week group swimming intervention for youth (aged seven to seventeen years) with CP using randomised controlled methods (Declerck et al., 2016). The authors reported that walking and swimming skills improved significantly in the intervention group compared to the controls, and that these improvements were maintained at 20 weeks. Furthermore, levels of enjoyment were rated as high, and there was no significant increase in pain or fatigue.

In summary, a small volume of evidence supports the use of swimming and aquatic exercise for individuals with disability. This evidence originates primarily from the paediatric field and, in particular, individuals with CP. Group interventions are proposed as a possible way of improving engagement.

Effects of swimming on health for the frail elderly

A consequence of ageing is the impaired ability of the central nervous system to secure and maintain body balance, and make requisite adaptive reactions (Avelar et al., 2010). This situation is further compounded by age-related sarcopenia (Bergamin et al., 2013), and the combined effects significantly increase the risk of falling (de Oliveira et al., 2014). The role of exercise in attenuating these age-related changes is well recognised (Cadore et al., 2013; Taaffe, 2006), and yet engagement with physical activity and sport is known to decline significantly in older adults (Hallal et al., 2012; Oja et al., 2015). This may, in part, be due to perception of risk and fear of falling (Sato et al., 2009).

The Concord Health and Ageing in Men Project studied a population-based cohort of 1,667 older men between 2005 and 2011, and examined the associations between common sporting activities and the incidence of falls (Merom et al., 2014). After adjusting for certain parameters, swimming was the only activity associated with a protective effect. Swimmers also demonstrated lower postural sway and a faster narrow walk test than men who only participated in lifestyle physical activities. The authors hypothesise that factors specific to swimming (improved core muscle function as a result of maintenance of a horizontal swim position, and increased ankle dorsiflexion and proprioception secondary to swim kick) may be implicated in the favourable results produced.

A number of intervention studies have described aquatic exercise and swimming as a therapeutic option for improving balance, enhancing strength and/or reducing risk of falling (Avelar et al., 2010; Bergamin et al., 2013; de Oliveira et al., 2014; Merom et al., 2014; Oh et al., 2015; Sato et al., 2009). These studies also indicate the ability of swimming/aquatic exercise to improve balance in older adults, although there were no additional benefits compared to land-based exercise in these studies (Avelar et al., 2010; de Oliveira et al., 2014). Gains in strength (hip abductors/adductors, knee extensors and ankle dorsiflexors) and improvements in physical functioning have also been described as a result of aquatic exercise training (Bergamin et al., 2013; Oh et al., 2015; Sato et al., 2009).

Rising life expectancy is associated with an increased prevalence of dementia; a recent meta-analysis estimated that there are over 9.9 million new cases of dementia diagnosed globally each year – one new case every 3.2 seconds (Prince et al., 2015). Furthermore, this number is projected to increase to 131.5 million by 2050 (Prince et al., 2015). Luengo-Fernandez et al. (2010) estimated that the health and social care costs for dementia almost match the combined costs for heart disease, stroke and cancer. A body of evidence is emerging that suggests exercise and physical activity may have a protective and disease-modifying influence for dementia (Ahlskog et al., 2011). Henwood et al. (2015) described a feasibility study, designed to influence physical performance and function, using an aquatic exercise programme for nursing home residents with moderate to severe dementia, low walking speed and sub-normal muscle strength. Two 45-minute aquatic exercise sessions per week were provided over a 12 week period. Eighteen participants started the programme, however eight were withdrawn for a variety of reasons. Post-intervention, a significant increase was demonstrated in grip strength, and positive (non-significant) trends in standing balance and step test. This study indicates that aquatic therapy for patients with dementia is feasible and safe, and warrants further investigation.

In summary, swimming appears to confer a significant protective effect in terms of reducing falls in elderly adults, and mitigating age-related frailty. Further, randomised trials of swimming as a fall prevention strategy are indicated. Swimming and aquatic exercise offer a potentially valuable strategy for re-engaging elderly adults with physical activity, in an environment that offers a greater margin of therapeutic safety. The influence of swimming and aquatic exercise on physical, cognitive and behavioural functioning in patients with dementia is an area for future research.

Effects of swimming on health for women

Physical inactivity levels increase with advancing age (Cox et al., 2008). In particular, disparities between physical activity levels in men and women are notable, with women being more likely to adopt sedentary behaviours (BHF, 2015). Swimming/aquatic and walking interventions are frequently advocated for older, sedentary women (ACSM, 2016). Cox et al. (2008) examined exercise adherence, in both the short and long term, to a six month supervised swimming or walking programme, followed by six months of the same programme unsupervised. Participants (n=116), were healthy sedentary women aged between 50 and 70 years who were randomly allocated to one of the two groups. Both modes of training were associated with good retention rates and adherence to exercise at six months (76.3% for swimmers versus 74.3% for walkers), and at twelve months (65.8% for swimmers versus 54.6% for walkers). Predicted barriers to adherence in the group of unsupervised swimmers (six to twelve month phase), such as difficulty finding a suitable pool/travelling to the venue or the cost of entry being prohibitive, were not realised in this study.

1. Effects of swimming on post-menopausal osteoporosis

Remaining physically active is of particular significance in post-menopausal women, as exercise is an important stimulus for the prevention and management of osteoporosis (Moreira et al., 2014). It is suggested that approximately 30% of post-menopausal women in the United States and Europe will develop osteoporosis, causing considerable morbidity, mortality and economic burden (Gómez-Bruton et al., 2013; International Osteoporosis Foundation, 2015). During physical activity, the effects of ground reaction forces and contractile forces from skeletal muscle promote osteogenesis, influencing bone mineral content and bone mineral density (Gómez-Bruton et al., 2013; Moreira et al., 2014). Given the reduced weight-bearing effect of the aquatic environment, some have suggested that swimming may have less osteogenic effects than higher impact sport, across all age ranges (Gómez-Bruton et al., 2013). A systematic review of 64 studies presented knowledge of the effects of swimming on bone mass, structure and metabolism in swimmers (Gómez-Bruton et al., 2013). The key findings were that swimmers demonstrated lower bone mineral density than individuals who engaged in high impact sport. Whilst swimmers' bone mineral density was comparable to sedentary controls, swimmers' bone turnover rate was higher. The authors suggest that this may result in swimmers having stronger bone structure, and therefore stronger bone, than sedentary controls.

Whilst physical activity clearly has a beneficial effect on osteometabolism, not all populations can tolerate high impact activities (Becker, 2009; Moreira et al., 2014). In these cases, aquatic exercise offers a viable alternative. A study of 108 post-menopausal women evaluated the effects of a 24 week high intensity aquatic exercise programme (Moreira et al., 2013). Participants were randomised to the intervention group or a sedentary control group. Findings demonstrated significant improvements in the intervention group for: rate of falls; flexibility; balance; strength and bone formation markers. In the control group, bone mineral density was reduced by 1.2% at the greater trochanter, however the swimming group showed no change. The authors concluded that the aquatic high intensity exercise programme was effective at attenuating bone resorption and promoting bone formation.

2. Effects of swimming during pregnancy

Swimming/aquatic exercise is one of the most common modes of physical activity selected by pregnant women in the UK (Liu et al., 2011) . It is believed to constitute a safe option as the aquatic environment reduces the chance of over-heating and the central blood volume expansion may be beneficial for utero- circulation during exertion (Lynch et al., 2007). A Cochrane review of aerobic exercise in pregnancy summarised that whilst there were positive effects for maternal physical fitness, the evidence was insufficient to infer risks or benefits to either mother or baby (Kramer and McDonald, 2006). Nonetheless, the American College of Obstetricians and Gynaecologists have recommended: *"Physical activity in pregnancy has minimal risks and has been shown to benefit most women, although some modification to exercise routines may be necessary because of normal anatomic and physiologic changes and fetal requirements. Women with uncomplicated pregnancies should be encouraged to engage in aerobic and strength-conditioning exercises before, during, and after pregnancy"* (ACOG, 2015). Lynch et al. (2007) investigated the efficacy of a second trimester swim training programme in 39 nulliparous, previously sedentary women. Twenty seven women were allocated to a swim group, twelve to a non-swimming comparator group. Results revealed a significant increase in cardiorespiratory fitness for the swim group, without any adverse effects for mother or baby.

Physical activity is also associated with the prevention of excessive weight gain in pregnancy (Barakat et al., 2012). Excessive maternal weight gain has been implicated in the development of gestational diabetes, with potentially adverse, short and long term, health implications for mother and infant. Studies investigating the efficacy of exercise training programmes (include aquatic training) in the prevention of gestational diabetes have demonstrated improved levels of maternal glucose tolerance.

Swimming and aquatic exercise is frequently recommended to pregnant women because of the reduced risk of falling, and the reduced risk of injury given hormonally driven ligament laxity (Melzer et al., 2010). A study conducted by Andersen et al. (2015) used self-reported data on pelvic girdle pain and information regarding physical exercise at around gestational week 16. Physical exercise was associated with a decreased risk of pelvic girdle pain. In particular, participants who selected swimming as physical exercise had lower odds for pelvic girdle pain than non-exercisers. This was not seen in other forms of exercise.

3. Effects of swimming and breast cancer

Breast cancer is the most common cause of cancer in the UK and will affect one in eight women over their lifetime (Cancer Research UK, 2015). There is an increasing interest in the importance of exercise therapy for women diagnosed with breast cancer, in particular aimed at modifying body composition (Fernández-Lao et al., 2013). Data suggests that women who are obese have a much greater risk of breast-cancer related mortality (Protani et al., 2010). Fernández-Lao et al. (2013) used a controlled clinical trial to compare an aquatic exercise programme, a land based programme and a control group for 98 breast cancer survivors. Results indicated that whilst land-based exercise was more effective at reducing body fat, aquatic exercise was superior in relieving breast symptoms in the short term. Aquatic exercise programmes have also been shown to be effective in reducing breast cancer-related fatigue (Cantarero-Villanueva et al., 2013) and hormone therapy-induced arthralgia (Cantarero-Villanueva et al., 2013).

In summary, swimming and aquatic exercise can make an important contribution to women's health. Swimming/aquatic exercise is a well-established physical exercise activity in pregnancy and appears to be a safe choice for women with uncomplicated pregnancies. Exercise in an aquatic environment also offers a safe environment for women at risk of/with established osteoporosis, and still confers benefits despite reduced weight-bearing status. Aquatic exercise also offers interesting options for symptom relief in individuals with breast cancer, although randomised controlled studies are required with longer term follow-up.

Summary and recommendations

As one of the most popular modes of physical activity, swimming/aquatic exercise confers significant physical health benefits for both healthy individuals and those with disease. Furthermore, these health benefits extend across the entire life-course – this chapter has presented evidence that demonstrates favourable effects of aquatic exercise from foetus through to the frail elderly.

Whilst there is a large body of literature considering aquatic exercise *per se*, there is relatively much less exploring the effects of swimming as a unique activity. It is imperative that this is addressed in future research, particularly given the compelling evidence presented that swimmers demonstrate lower all-cause mortality rates, and reduced incidence of falls in later life.

Many of the studies presented have methodological limitations – future studies of swimming and aquatic therapy should ensure larger sample sizes, especially where exploring the effect on modifiable risk factors. A focus on programme intensity, frequency and design for optimal physical health benefits, as well as longer-term effectiveness, would be of significant value for clinical and public health arenas.

The unique nature of the aquatic environment as a medium for exercise and physical activity has been comprehensively described. What is evident is that water-based exercise can confer a number of specific advantages, as compared to land-based exercise. As an environment that offers reduced weight-bearing stress, higher humidity levels, decreased heat load and a greater margin of therapeutic safety in terms of falls-risk, swimming/aquatic exercise is extremely well-placed to safely and effectively meet the needs of a wide-range of individuals, in both the treatment and prevention of physical health issues. Water-based exercise prescription should be a key consideration for health care clinicians and commissioners.

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Chapter 2

The wellbeing benefits of swimming: a systematic review

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Key words:

swimming
wellbeing
health
quality of life
mental health

Introduction

There is an increasing recognition of the importance of maintaining and promoting the wellbeing of individuals within society and the entire lifespan (Naci and Ioannidis 2015). With unprecedented changes in global demographics including the fact people are living longer, yet with more years of disability (Vos, Flaxman et al. 2013) and an increasing number of mental health problems across the lifespan (Whiteford, Degenhardt et al. 2013), the need for strategies to maintain and improve wellbeing are fundamental for individuals and the communities they reside (Lovell, Wheeler et al. 2014). The World Health Organisation (WHO) state that promoting wellbeing across the lifespan should include a multitude of factors including tackling poverty, food and water shortages, appropriate management of disease, infrastructure and lifestyle behaviours (World-Health-Organisation 1998). Set within this context, is the growing realisation that physical activity, sport, leisure and exercise can play an integral role in achieving the wellbeing agenda (Eime, Young et al. 2013).

In the wider physical activity literature, there is an abundance of evidence demonstrating that physical activity and exercise positively influence wellbeing (Netz, Wu et al. 2005, Penedo and Dahn 2005). For instance, physical activity, including outdoor fitness programs and exercise has been shown to improve social and emotional wellbeing among youth who may be at risk of poor mental health outcomes (Lubans, Plotnikoff et al. 2011). A landmark study published in the Lancet conducted among 2,223 boys and 2,838 girls aged 16 demonstrated that vigorous participation in sports was positively associated with emotional wellbeing (Steptoe and Butler 1996). Moreover, physical activity has been shown to positively improve the wellbeing of specific groups such as veterans with post-traumatic stress disorder (Caddick and Smith 2014), people with depression (Schuch, Vancampfort et al. 2016), people in prison (Woods 2017) and young people using wheel chairs (O'Brien, Noyes et al. 2016). At the other end of life's spectrum, a previous systematic review (Windle, Hughes et al. 2010) found that two sessions of exercise a week for 45 minutes can significantly improve the wellbeing of older people (standardised effect size = 0.27; CI = 0.14-0.40). Moreover, the authors indicated that there was evidence of an incremental cost-effectiveness ratios (compared with minimal intervention) of £7,300 and £12,100 per quality adjusted life year gained for community-based walking and exercise programmes, respectively (Windle, Hughes et al. 2010).

Swimming remains one of the most popular forms of physical activity across the world (Hulteen, Smith et al. 2017) and may offer a unique opportunity to promote, maintain and improve wellbeing across the lifespan, with potential to reach all individuals of society, regardless of gender, age, disability or socioeconomic status (Lee and Oh 2013). Despite the aforementioned established wellbeing benefits of physical activity more broadly, the literature considering the potential wellbeing benefits of swimming among individuals in society has to the best of our knowledge not been synthesised previously. With this in mind, the current chapter provides a synthesis of findings from a comprehensive systematic review of 4,352 de-duplicated articles within the literature to answer the following questions:

1) What is the evidence for swimming across the lifespan from 'cradle to grave' (including children, adolescents, working age and older age) on wellbeing?
2) What is the evidence for swimming and aquatic exercise to improve wellbeing across general specific populations who may particularly benefit from water based activities?
3) What are the gaps within the literature and important questions for the future?

The final section of the chapter includes a consideration of the gaps in the knowledge base of swimming and wellbeing in addition to recommendations and visions for how swimming can meet the pressing desire to promote the wellbeing of all individuals across society.

What is wellbeing and why is it important?

There has been growing interest in the concept of wellbeing, with particular momentum since the previous millennium (Lindert, Bain et al. 2015). This is for good reason, since wellbeing is associated with good self-rated health, longevity, healthy lifestyle, better mental and physical health, social connectedness and a feeling of the ability to contribute to wider society (Lindert, Bain et al. 2015). A previous meta-analysis demonstrated across 35 studies that good psychological wellbeing was associated with an 18% reduction in premature mortality compared to those with poor wellbeing in the general population (Hazard Ratio 0.82; 95% Confidence Interval (CI) = 0.76-0.89; p < .001) (Chida and Steptoe 2008). Moreover, individual components of wellbeing such as happiness and contentment are associated with positive health outcomes (Graham 2008) and a reduced odds of developing a mental illness (Weich, Brugha et al. 2011). Perhaps unsurprisingly, many national bodies, including the UK government (Department of Health 2014) and International bodies such as the World Health Organisation (WHO) (World Health Organisation 1998) recognise that promoting and maintaining wellbeing is of utmost importance.

Despite the uniform consensus on the importance of wellbeing, there continues to be a lack of agreement regarding a definition of wellbeing and how best to measure and monitor this construct (Dodge, Daly et al. 2012). This is personified in a recent systematic review, which focussed only on "subjective wellbeing" and identified 60 different scales had been used in the literature and found that the majority of studies used a heterogeneous definition of wellbeing (Lindert, Bain et al. 2015). Nonetheless, wellbeing is often interlinked or used interchangeably with quality of life (QOL), happiness, positive mental health, healthy ageing and is regarded as a higher order construct (Diener 2000, Lindert, Bain et al. 2015). A definition from the United Kingdom (UK) Government is "*Wellbeing is about feeling good and functioning well and comprises an individual's experience of their life; and a comparison of life circumstances with social norms and values*" (Department of Health 2014). At its simplest, wellbeing can be defined as feeling good and judging life positively (Veenhoven 2008). A recent systematic review on subjective wellbeing measurement for the WHO health policy unit defined wellbeing as *"a cognitive process of contentment, satisfaction or happiness derived from optimal functioning. Optimal functioning is a relative rather than an absolute concept as the benchmark for judging lies in an individual's perception of his or her own aspirations*" (Lindert, Bain et al. 2015).

Wellbeing extends beyond the typical boundaries of good health, in that it incorporates other facets including physical vitality, cognitive alertness, feeling connected, mental health, social satisfaction, a sense of accomplishment, personal fulfilment and purpose (Naci and Ioannidis 2015) It also encapsulates areas of life such as feelings of satisfaction, optimism, self-esteem, having control over one's life, having a purpose in life and a sense of belonging (Department of Health 2014). There is consensus that wellbeing is a multifaceted construct, which consists of a subjective component (for example an individual's own perception of their health state and happiness) and an objective component (for example captured by expert checklists, e.g. Warwick and Edinburgh Mental Wellbeing Scale (Tennant, Hiller et al. 2007) (Department of Health 2014)).

In summary, wellbeing is a positive outcome that is meaningful for individuals and for society, because it informs us about how well people perceive their lives are and if they are content (Tennant, Hiller et al. 2007, Weich, Brugha et al. 2011, Naci and Ioannidis 2015).

Why might swimming or water based activities be good for wellbeing?

As is evident from the literature, there is robust evidence that engaging in physical activity is good for wellbeing (Steptoe and Butler 1996, Netz, Wu et al. 2005, Penedo and Dahn 2005, Windle, Hughes et al. 2010). The well-established definition of physical activity is "*any bodily movement produced by skeletal muscles that results in energy expenditure*" (Caspersen, Powell et al. 1985) and clearly swimming fits within this definition or that of exercise. The potential for swimming to improve wellbeing is considerable. Swimming is an activity that people can participate in regardless of age, ethnicity and culture and may offer a unique strategy for people to engage in a meaningful form of physical activity (Oh and Lee 2015). Moreover, unlike many other sports (for example football, golf, squash), swimming is considered to be more inclusive across genders (Thomson, Kearns et al. 2003). There has been a growing interest within the literature over the last 30 years, suggesting that swimming can improve an individual's health and reduce stress compared to other sports (Lee and Oh 2014). However, robust quantitative data is still lacking at this moment in time to confirm or refute such long held beliefs. Whilst not a wellbeing construct per se, a recent study of over 80,000 adults suggested that swimming may offer a protective effect from early all-cause and cardiovascular cause death, with a more protective effect evident compared to other sports (Oja, Kelly et al. 2016). The unique opportunity for swimming to improve wellbeing also stems from its popularity, with a recent global meta-analysis demonstrating that swimming is particularly popular among young people (Hulteen, Smith et al. 2017). Swimming is also very popular in England, with national data from the Active People Survey by Sport England (Sport England 2016) demonstrating that between October 2015 and September 2016, 2,516,700 people aged 16 years or older reported swimming (including all swimming and diving (indoor and outdoor), water polo, deep water swimming, open water swimming, deep water diving) at least once a week. It has been established in previous research, that personal preference, enjoyment and choice is a key factor to determine long term adherence to a physical activity/sport and thus receive the long term health and wellbeing benefits (Rhodes, Martin et al. 1999, Ekkekakis and Lind 2006). *Therefore, the relative popularity of swimming across the lifespan indicates that swimming may offer an unrivalled opportunity for individuals to remain engaged in long term physical activity*.

Anecdotal commentaries suggest that swimming can be fun, improve longevity and it can have benefits across the lifespan and be adapted to meet the needs of all sectors of society (Hetzler 2013) although scientific data is currently lacking to confirm/refute such statements. However, some authors have suggested that compared to other sports and leisure activities, swimming is very low risk in terms of injury (Oh and Lee 2015), although again there is a lack of scientific data on this subject. Moreover, swimming may be conducive to engagement as a form of physical activity when an individual may have a particular injury or ailment (for example osteoarthritis or low back pain) which may preclude participation in other activities and also form an integral part of an individual's rehabilitation and recovery (Bidonde, Busch et al. 2014).

All of these factors, suggest that swimming offers a unique opportunity for people of all ages and abilities, the possibility to enhance their wellbeing and psychological health through physical activity (Oh and Lee 2015). Swimming pools and facilities can offer a way of meeting an individual's social, emotional and cultural wellbeing (Hendricks et al 2016). In addition, other forms of immersion and swimming in natural water can also offer wellbeing benefits to the individual particularly when in outer spaces (Foley 2015). In light of this, Swim England has suggested in its report "*Swimming: Taking the plunge for a fitter lifestyle*" (Amateur Swimming Association (ASA) 2014) that swimming can play a central role in meeting the wellbeing and social health needs of the population. Specifically, the ASA report identified that swimming can:

- Soothe the mind and reduce anxiety
- Relax the body
- Support the body in a relatively weightless environment
- Offer opportunities to socialise. Swimming pools are meeting points
- Reduce loneliness and introduce friends
- Contribute to creating a sense of place and promote swimming pools as places to go.

However, at this time, there is insufficient robust data, published in peer reviewed journals to confirm/refute these potential benefits. Thus, future research is required to confirm such beliefs, values and statements.

Despite the potential benefits of swimming, there are some alarming changes in the number of people taking part in swimming which should serve as a severe strategic warning to society, communities and individuals. Previous data on swimming practices in England from October 2005 to September 2006 found that 3,273,800 people age over 16 years engaged in swimming, which is just over 750,000 less people engaging in weekly swimming compared to current figures (Sport England 2016). Thus, at a time when promoting wellbeing is a national (Department of Health 2014) and International (World Health Organisation 1998) priority, never has there been a more pressing time to explore and raise awareness of the importance of swimming to meet the potential individual wellbeing benefits of swimming. The recent global meta-analysis of sport and leisure participation rates (Hulteen, Smith et al. 2017) demonstrates that swimming was a top five sport in all world geographical regions in childhood, but dropped outside the top five commonly participated sports in all geographical areas except the Eastern Mediterranean and Western Pacific in adulthood.

Clearly an urgent area for future research is to understand why swimming levels are dropping generally, but specifically consider why swimming participation rates become notably less popular in the progression to adulthood. At this moment in time, no quantitative research is available informing researchers/policy makers why numbers participating in swimming are dropping and investigation of this should be considered a priority. Future qualitative work may also consider why frequent swimmers decided to stop, which should inform future public health interventions and prevent the current haemorrhaging of swimming participation observed in society.

What does the evidence say for the wellbeing effects of swimming across the lifespan and in special populations?

The next section is dedicated to a review and critique of the reported literature on the potential wellbeing benefits across specific populations.

Children

There are rising concerns about the increasing levels of sedentary behaviour and low levels of physical activity in young people which is associated with worse physical, mental, social and wellbeing outcomes (Strong, Malina et al. 2005, Van Hecke, Loyen et al. 2016). There is good evidence from systematic reviews that engaging in physical activity and sport can improve mental health (including reducing depression and anxiety), self-esteem, cognitive performance and academic achievements (Biddle and Asare 2011). Thus, it is reasonable to hypothesise that swimming could play a pertinent role in helping children become more active, feel connected with their peers and improve wellbeing outcomes. However, the evidence at this stage is largely circumstantial and indirect with virtually no robust evidence directly attributing swimming has a positive influence on wellbeing in children. However, one should not mistake an absence of evidence as meaning swimming does not have wellbeing benefits. Although it indicates that robust evidence on swimming, wellbeing and childhood is required as a matter of priority.

Nonetheless, promoting swimming in childhood is the optimal time to provide a positive experience for children to begin the swimming and wellbeing journey. In fact, young people tend to have higher participation rates in swimming compared to adults and it is a vital time to harness and maintain this over the lifespan and tackle health inequalities early on (Audrey, Wheeler et al. 2012). Thus, providing access and opportunities for young children to swimming is the prime time to provide the catalyst for a lifetime of swimming and the associated wellbeing benefits. Moreover, having positive swimming experiences in childhood reduces the likelihood of developing a fear of water in adulthood (Poulton, Menzies et al. 1999), thus emphasising the importance of beginning swimming in adolescence.

A recent study in a large city in England investigated the impact of the local authority providing free swimming passes to 1,011 young disadvantaged children in a pre and post-test study (Pringle, Zwolinsky et al. 2014). The authors found that providing free swimming passes helped increase self-report physical activity levels among children, with the most notable improvements seen among those who were sedentary or insufficiently active at baseline (Pringle, Zwolinsky et al. 2014). The greatest effect was seen among young girls and not boys who tended to be more active at baseline. Whilst it might be a reasonable assumption to join the dots and assume that since this study found an increase in self-report physical activity (which has established wellbeing benefits in this group (Biddle and Asare 2011, Lubans, Richards et al. 2016)), that this equals an improvement in wellbeing, the authors did not collect information on wellbeing. Moreover, there is no robust data available demonstrating the direct benefit of swimming on wellbeing in children in the general population available in the literature.

Cognition in children

One of the key components of wellbeing is good cognitive health (Naci and Ioannidis 2015). There is a considerable amount of literature demonstrating that physical activity and sport participation are good for the cognitive health of children, including academic performance, confidence and happiness (Esteban-Cornejo, Tejero-Gonzalez et al. 2015, Lubans, Richards et al. 2016). In particular, it appears that vigorous physical activity, which could include competitive swimming, may have the largest impact on cognition in adolescents (Esteban-Cornejo, Tejero-Gonzalez et al. 2015). However, there is a paucity of studies that have specifically investigated the relationship of swimming on cognition in adolescents to date, thus precluding any definitive conclusions being made. However, one study provides a partial insight (Lee, Wong et al. 2014). The authors recruited adolescents who had in the past two months completed some/all of the following: intensive rowing, swimming and triathlon training and compared their neurocognitive performance versus age and sex matched controls that were not engaging in regular exercise. The authors found that frequent exercisers (which could have been any of the aforementioned activities) had better cognitive performance, which they state may have been attributed to increases in brain derived neurotrophic factor. However, it is not possible to confirm/refute whether the differences in cognition among "swimmers" and controls were actually due to swimming for a number of reasons. First, the differences in cognition could be due the other types of exercise (for example rowing participation) or other random confounders such as differences in education, social class or intelligence among many others. Second, this is a cross sectional study, which precludes any inferences to be made such as swimming may have contributed to cognition. Only future controlled trials, whereby adolescents are randomly allocated to swimming or no activity and followed up over time can make claims about the potential direct benefits of swimming on cognition.

In 2013, a study into the cognitive benefits of swimming lessons for children (Jorgensen 2013), reported that children participating in regular swimming lessons achieved a range of developmental milestones much earlier than the wider population regardless of socio-economic background or gender. Swimmers were between six and twelve months ahead of the norm in physical skills, cognitive skills, mathematics, language development, counting and ability to follow instructions ($p<0.001$). These areas were considered to be the key skills utilised in "formal education contexts" which, the authors believe, may give swimmers a "considerable advantage" as they start their academic studies. Whilst informative, this research is not published in a peer review journal and is a survey design with no randomisation or specific intervention (e.g. randomising children to swimming and not swimming would enable assertions to be made about causation), meaning the results acquired could potentially be attributed to many other factors, including chance.

In summary, there is an alarming dearth of robust evidence demonstrating the benefits of swimming in children for wellbeing. Future research is required to evaluate the potential benefits in cognition and wellbeing for adolescent swimmers using robust study designs. Nonetheless, even in the absence of swimming specific evidence, swimming could be considered a valuable approach to improve wellbeing given the irrefutable literature of the importance of physical activity in this group more generally (Biddle and Asare 2011, Lubans, Richards et al. 2016).

Adults

Swimming in working and middle age may be a highly desirable form of physical activity to improve wellbeing since it enables the individual to swim at their own pace without putting great pressure on joints like ground exercise (Lee and Oh 2013). There is however, a paucity of studies evaluating the wellbeing effects from swimming in the general adult's population (specific populations are considered below). A survey study among 200 females aged 40-60 years across five cities in Korea suggested that participation in swimming was associated with improved life satisfaction, mental health and self-perception of health (Lee and Oh 2013). A study of 300 adults reported that participating in swimming lessons was associated with better self-rated health, including better psychological health, reduced levels of stress and lower levels of disability (Oh and Lee 2015). Thus, there is some evidence in the general population that swimming is associated with better self-reported wellbeing and outcomes. However, these inferences are based on poor quality evidence (for instance cross sectional/retrospective studies), precluding any firm conclusions that swimming specifically improves wellbeing in adults.

Older adults

There is growing recognition that the number of older people is significantly rising as life expectancies increase across the world and the United Kingdom (Salomon, Wang et al. 2013). Physical activity, a sport and leisure have an integral component in promoting healthy ageing and wellbeing (Windle, Hughes et al. 2010, Stubbs, Chen et al. 2017). Thus, swimming has the potential to meet the wellbeing needs of the growing older adult population. However, there is a severe lack of evidence demonstrating the specific benefits of swimming in the general older adult population.

One study found that regular older swimmers (n=16) who reported swimming between two and five times a week over a period on average of 2.5 years, had significantly better executive function on three tasks, compared to sedentary older adults of similar age and gender who did not swim (Abou-Dest, Albinet et al. 2012). Interestingly, the authors observed that the better improvements in executive function among swimmers were not attributed to cardiorespiratory fitness. This longitudinal study provides some interesting evidence, but the very small sample size precludes any meaningful conclusions being drawn.

Aquatic exercise for medical conditions: chronic musculoskeletal conditions

There is robust evidence demonstrating that people are living longer, yet with more years with disability and chronic musculoskeletal conditions such as osteoarthritis or low back pain are leading contributors to this burden (Vos, Flaxman et al. 2013, Smith, Hoy et al. 2014). Swimming and aquatic exercise may have considerable potential to help address this burden and improve quality of life and wellbeing. A systematic review of seven studies found that aquatic exercise may improve disability and pain in people with low back pain but offered no data on wellbeing constructs (Waller, Lambeck et al. 2009). A recent Cochrane review found some evidence that aquatic exercise improved anxiety symptoms (standardised mean difference (SMD) -0.57, 95% CI -0.95 to -0.19, 7 studies) and sleep (SMD -0.63, 95% CI -1.12 to -0.14) among people with fibromyalgia (Bidonde, Busch et al. 2014). However, no influence was observed on mental health (mean difference (MD) =-3.03, 95% CI -8.06 to 2.01, four studies), self-efficacy (MD=MD 9.54, 95% CI -3.39 to 22.46, two studies, 88 participants) or fatigue (SMD -0.31, 95% CI -0.75-0.13).

A Cochrane review suggested that aquatic exercise has a small improvement on quality of life among people with hip or knee osteoarthritis (SMD = 0.25, 95% CI -0.49 to -0.01, 10 studies) (Bartels, Juhl et al. 2016). A randomised trial investigated the benefits of 20 swimming sessions over 4 weeks versus usual care among people with ankylosing spondylitis (Dundar, Solak et al. 2014). The authors found that people engaging in aquatic exercise had better vitality ($p < 0.001$), social functioning ($p < 0.001$), role limitations due to emotional problems ($p < 0.001$), and general mental health ($p < 0.001$) scores at 4 and 12 weeks compared to their baseline scores. Aquatic exercise may also help young people with juvenile idiopathic arthritis, with a controlled trial over 20 sessions suggesting that aquatic exercise may improve physical and psychological quality of life (Takken, Van Der Net et al. 2003).

Aquatic exercise for medical conditions: other medical conditions

A preliminary meta-analysis of three studies suggested that aquatic exercise offered no advantage over land based exercise to improve quality of life among people with heart failure (Adsett, Mudge et al. 2015). A recent small (n=21) pilot controlled trial found that two 45 minute aquatic exercise sessions for 6 weeks did not improve quality of life among people with early stage Parkinson's disease versus usual care (Carroll, Volpe et al. 2017). A pre- and post-test study with no control group found some suggestion that aquatic therapy may improve quality of life and physical activity levels among 18 men with type 2 diabetes (Cugusi, Cadeddu et al. 2015).

Pregnancy

It was not possible to identify any specific studies considering the potential wellbeing effects of swimming on pregnancy. However, a recent large Danish birth cohort study (n= 78,486) found that compared to women who did not swim, women who swam in early/mid-term had a slightly reduced risk of giving birth pre-term (hazard ratio (HR) 0.80, 95% CI 0.72-0.88) or giving a birth to a child with congenital malformations (HR 0.89, 95% CI 0.80-0.98).

Multiple sclerosis

Multiple sclerosis (MS) is a relapsing and remitting progressive neurological disorder that affects the brain and spinal cord and typically results in loss of muscle control, balance and altered sensation (Kargarfard, Etemadifar et al. 2012). Given this, it is perhaps unsurprising that the wellbeing of people with is often affected, requiring the potential input of safe and effective interventions to address this (Dehnavi, Heidarian et al. 2015). A recent aquatic exercise program in a swimming pool over 8 weeks, including three sessions a week lasting 60 minutes found that exercise in the swimming pool improved multiple wellbeing domains (Kargarfard, Etemadifar et al. 2012) . Specifically the study found that the aqua exercise improved mental health, health perception, energy levels, fatigue, emotional health and possibly cognitive function.

Cancer

An eight week randomised control trial of aquatic exercise for cancer (Cantarero-Villanueva, Fernandez-Lao et al. 2013) among 68 breast cancer survivors were randomised to aquatic exercise group in deep water pool or a control (usual care) group. The intervention group attended three times a week, for 60 minutes for 8 weeks in a structured aquatic exercise in a local swimming pool. The study found that aquatic exercise significantly improved fatigue, cognition/mood with a small improvement in reduced depression symptoms (Cantarero-Villanueva, Fernandez-Lao et al. 2013). Whilst there were these improvements immediately after the intervention, the results were attenuated at 6 month follow up.

Another RCT among 42 breast cancer survivors investigated a multimodal physiotherapy program which included aquatic deep water running (Cantarero-Villanueva, Fernandez-Lao et al. 2013). The intervention included traditional physiotherapy and deep water running for one hour for three times a week over eight weeks delivered by physiotherapists. The results found that compared to usual care, the intervention group had improvements in fatigue (Cohens D =0.69, $p<0.001$), affective meaning (D=1.0, $p<0.01$), sensory (D=0.26, $p=0.04$) but no change in cognition. The exercise group also had significant improvements in physical quality of life (D=0.59, $p<0.01$), mental quality of life (D=0.50, $p<0.001$), and overall QOL (D=1.35, $p<0.001$). There was no longer term follow up and it remains unclear if the improvements can be actually attributed to aquatic running.

Mental health

There is now strong evidence that physical activity can prevent the onset of depression (Mammen and Faulkner 2013) whilst inactivity increases the risk of developing anxiety reduced mood (Endrighi, Steptoe et al. 2015, Teychenne, Costigan et al. 2015). Moreover, there is strong evidence that exercise can improve mental health symptoms for people with depression (Schuch, Vancampfort et al. 2016), quality of life (Schuch, Vancampfort et al. 2016) and symptoms of anxiety and stress (Stubbs, Vancampfort et al. 2017). Thus, there is considerable potential for swimming to improve the wellbeing with people with mental illness and poor mental health. However, there are no studies specifically measuring the influence of swimming on wellbeing among people with mental health conditions in the literature. Nonetheless, a report by the Mental Health Charity "Mind" states that swimming is good for people's mental health and wellbeing and recommend swimming as an approach (MIND). Considerations reported by Mind include the fact that people may be nervous about body image. Body image within the context of swimming can act as a barrier to participation since people who are anxious about how their body will look to others, while they are exercising, and may avoid swimming. It has been suggested that having a buddy to attend swimming, or for ladies attending a women only swimming session can help swimming participation and any social physique anxiety (MIND, Soundy, Freeman et al. 2014).

Future research should investigate the potential benefits of swimming for people with mental illness.

Dementia and cognitive decline

There is increasing recognition that as people are living longer, the number of older people who will be affected by cognitive decline and dementia is subsequently rising (Prince, Ali et al. 2016). People with dementia are at increased risk of having a number of physical comorbidities, declining physical capabilities and increasing frailty (Bunn, Burn et al. 2014). Consequently, people with dementia may have reduced wellbeing and social interaction and there is a pressing need for meaningful activities to promote better wellbeing in this group (Nyman and Szymczynska 2016). Swimming is one potential strategy that can help improve the wellbeing of those with dementia, with particular benefits among those who have previously engaged in swimming in the past (Neville, Clifton et al. 2013). Swim England is leading the way forwards and suggests that swimming can play a central part in meeting the wellbeing needs of people with dementia (Amateur Swimming Association, 2014). Currently, Swim England has developed the Dementia Friendly Swimming Project to help enhance the swimming experience of those living with dementia and their carers by improving facilities and removing barriers to participation (Dementia Action Alliance 2017). Over this three year project, Swim England hope to be working with over 100 swimming pools, training 300 key swimming staff and 300 staff in front line roles, and developing 60 cascade courses to aid sustainability. In addition, the project will seek to positively enhance the swimming experience for more than 3,000 people living with dementia and 1,500 adult carers (Amateur Swimming Association, 2014). To date, robust data considering the potential wellbeing effects of such initiatives are not publically available.

In the research literature, one venture seeking to promote wellbeing through swimming in dementia is the Watermemories Swimming Club in Australia, which is a swimming club designed to increase physical exercise while being easy to implement, safe, and pleasurable (Neville, Clifton et al. 2013). In an evaluation of the 12 week swimming Watermemories Swimming Club, 11 people with dementia from two care facilities were recruited and supported to swim for up to 45 minutes (Neville, Henwood et al. 2014). The authors found that over a 12 week period, the swimmers with dementia had a significant improvement in psychological wellbeing. The authors suggest that the improvement in psychological wellbeing could be attributed to the exercise from swimming in addition to the socialisation, rekindling of positive memories, fun and relaxation. Importantly, the participants with dementia also experienced a reduction in behavioural and psychological symptoms of dementia, including those which were troubling to their carers (Neville, Henwood et al. 2014). In a separate publication, the authors noted that attending swimming also resulted in an improvement in a number of physical performance measures including grip strength (Henwood, Neville et al. 2015). Given the positive results, the authors have called for a larger randomised control study to be conducted. The authors also provide some helpful considerations from their experience of running the Watermemories Swimming Club including ensuring that swimming facilities should be carefully chosen have disabled access, heating, adequate changing area and appropriate floating devices among others (Neville, Clifton et al. 2013).

Future, robust evaluation studies are required to determine the benefits of swimming among people with dementia. There is no reliable data within the UK context at this moment in time, despite commendable efforts to increases participation among this population.

Cerebral palsy, learning disabilities and autism

Children with cerebral palsy often have a range of motor progressive changes that can impair ones quality of life and wellbeing (Liptak 2008). Moreover, as children with cerebral palsy progress in adulthood, they can have reduced functioning, mobility, experience social isolation and reduced social interaction (Liptak 2008). Thus swimming, particularly in childhood, is important for this groups individual wellbeing and social interactions. A systematic review published over ten years ago found some preliminary evidence that swimming and aquatic exercise may improve respiratory function and possibly activity levels in children with neuromotor impairments (mainly cerebral palsy) (Getz, Hutzler et al. 2006). The authors noted there were no harmful effects of aquatic interventions and called for more robust research to confirm their preliminary evidence. A more recent systematic review found aquatic exercise improved gross motor skills including walking speed (Roostaei, Baharlouei et al. 2016). A recent controlled cross over study (Declerck and P 2014) among fourteen children with cerebral palsy demonstrated that there participation in swimming was associated with a trend for improvements in motor abilities, social function and suggested that swimming could be an important strategy to prevent the deconditioning common among those with Cerebral Palsy. Moreover, the authors noted that the children had high levels of adherence and enjoyment with improvements noted in high levels of adherence, low adverse events and was greatly enjoyed by participants. In another study, aquatic therapy was shown to improve motor control, social functioning, emotional wellbeing and actual physical activity levels (Lai, Liu et al. 2015).

A 16 week swimming training program demonstrated that swimming may be a useful way to help children with intellectual disabilities to safely lose weight (Casey, Rasmussen et al. 2010). Losing weight has been shown to be associated with improvements in cognition in the general population and may therefore be useful in this aspect of wellbeing (Veronese, Facchini et al. 2017). Moreover, there is strong evidence from an umbrella review that adiposity is associated with an elevated risk of eleven cancers (oesophageal adenocarcinoma, multiple myeloma, and cancers of the gastric cardia, colon, rectum, biliary tract system, pancreas, breast, endometrium, ovary, and kidney) and losing weight may therefore reduce the risk of cancer (Kyrgiou, Kalliala et al. 2017). Some children with cerebral palsy may be particularly scared of getting into the water, but this can be overcome as was evidenced in a 14 week swimming study where children's confidence improved quickly after the first introductory week of a session (Ozer, Nalbant et al. 2007). Finally, a study intervened through swimming (Pan 2010) and then examined the impact on social-emotional behaviour. The effect size of this intervention was 0.6, indicating a moderate improvement in social-emotional behaviour.

Specialist populations: black, minority ethnic and hard to reach groups

Over the past twenty years or so there has been an increasing emphasis on the importance of increasing physical activity and sports engagement among Muslim youth (Hamzeh and Oliver 2012). A recent qualitative study demonstrated that Muslim young females can find swimming challenging due to their beliefs and in particular find the notion of wearing swimsuits in front of their peers or others a challenge (Hamzeh and Oliver 2012). Another study across three University of Washington swimming centres which were exclusively restricted to Somali immigrants (Moore, Ali et al. 2010) provided an evaluation of free swimming sessions. Overall the authors reported that twenty six swim events were held in just under two years, including nine swim lessons, four water safety lessons and two water aerobic classes with a mean of 30 people attending each event. Overall 52 men and 29 women completed a survey and 89% said they would not attend if the opposite sex was in attendance too. Respondents also reported they were keen to keep attending to engage in physical activity even if they were not able to swim. These examples provide evidence that it is possible to engage hard to reach groups and cater for their particular needs and support them to attending swimming. However, there is no data specifically illustrating how providing free swimming did/did not influence wellbeing. Thus, going forwards, such UK initiatives should adopt a more robust approach to capture the potential wellbeing benefits from swimming participation.

Reaching ostracised groups – A case study of Aboriginal people

It is well established that marginalised groups in society tend to have worse wellbeing and engage in lower levels of physical activity (Gracey and King 2009, Gracey 2014). A pertinent example of how swimming can reach ostracized groups within society who have profound health inequalities and social isolation is within the context of aborigines. Aboriginal people die decades before members of Australian general population due to socioeconomic and environmental disadvantage, inadequate education, underemployment, racial prejudice, high-risk health-related behaviours and limited access to clinical services and health promotion programmes (Gracey 2014). A recent systematic review (Hendrickx, Stephen et al. 2016) including twenty studies found some evidence that providing swimming pools for aboriginal people had a range of social and emotional wellbeing benefits including improved school attendance among children, better water safety and social connection. In particular it was noted that swimming pools can provide an important hub where families can come together in a safe environment and enjoy positive relationships. Moreover, among the young aboriginal children, access and attendance at swimming pools may possible reduce their involvement in petty crime and keep them on the 'straight and narrow' (Hendrickx, Stephen et al. 2016).

In a local UK example, an in-depth qualitative study across two deprived neighbourhoods in Glasgow, provides compelling insight into the value of having access to a local swimming pool (Thomson, Kearns et al. 2003). The authors illustrated that whilst people in the deprived areas recognised and valued the benefits derived from physical activity, a greater emphasis was placed by the local people on the wellbeing and mental health benefits from swimming (Thomson, Kearns et al. 2003). Specifically, participants noted that attending the swimming pool provided a unique opportunity to improve their mental health, reduce stress and provide an opportunity to allow the individuals to be relieved from disadvantages and isolation.

Thus, it appears that ensuring access to swimming pools may provide a unique opportunity for individuals to feel good about themselves, provides a point of contact with others and forget about their current problems they may be facing, which may not be possible from other types of sport or leisure. In addition to such fascinating qualitative insights, future intervention research that includes providing free swimming to those from disadvantaged backgrounds should focus on capturing the wellbeing benefits through recognised outcomes measures such as the Warwick and Edinburgh Wellbeing Scale (Tennant, Hiller et al. 2007).

Summary and recommendations

There is growing recognition that exercise can cross many boundaries and meet the wellbeing needs of the population from the cradle to grave. However, there is a dearth of research specifically considering the wellbeing benefits of swimming among the general population. The literature is also incredibly difficult to locate due to poor indexing in electronic databases. For instance, a search on the "bible" of health and medical databases with the broad terms of "swimming and wellbeing" identifies only 16 potential articles (as of 1.4.2017). To date, the literature considering the wellbeing benefits of swimming in the general population is largely circumstantial and relies on "leaps of faith" drawing from indirect inferences from the general benefits of physical activity and exercise. There is however promising evidence that aquatic exercise can improve quality of life in people with osteoarthritis, some other musculoskeletal disorders and people after cancer. There are several important initiatives happening (for example Dementia Friendly Swimming) and it is essential, that this is accompanied by robust evaluation, so that further opportunities to demonstrate the value of swimming are not missed.

Recommendations

- There is an urgent need to investigate why there is a drastic haemorrhaging in the numbers of people swimming in general and in the transition from childhood to adulthood.

- Investment in research is required to investigate the wellbeing benefits of swimming across the lifespan in the general population, with a particular focus on mental health, emotional health and subjective wellbeing. Understanding and relaying this information may potentially help participation with the considerable public interest in the wellbeing value of specific activities.
- More research is particularly required to consider the wellbeing benefits of swimming on people with mental health conditions, people with learning disabilities (including Downs Syndrome), older adults with and without dementia and other ostracised groups such as black and minority ethnic groups, homeless people and those who are isolated and identified as being lonely.
- Targeted pragmatic evaluations of "hot" initiatives, such as the dementia friendly swimming, are required to document potential improvements in wellbeing. This could also include addressing social inequalities and promoting participation among ostracised groups such as the homeless, migrants and vulnerable children and adults at risk of poor wellbeing and health.

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Appendix

Methods

The current systematic review was conducted in accordance with best practice, namely the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Statement (PRISMA)[1]. A pre-specified but unpublished protocol was adhered to as set out below.

Eligibility Criteria

Studies were considered eligible if they met the following criteria:

Population – People of any age, gender and ethnicity were eligible. In addition to the general population, studies in potentially vulnerable populations such as learning disabilities, downs syndrome, dementia and people with any type of disability were sought.

Intervention – Studies considering any type of swimming or aquatic activity (structured or unstructured) in a swimming pool or natural waters (e.g. lake, sea) were considered. This review also included non-quantitative (e.g. qualitative) studies considering people's experience of swimming and wellbeing.

Comparator – Studies investigating swimming benefits or experience of wellbeing with and without any comparison group are eligible.

Outcomes – Any quantitative or qualitative study reporting wellbeing as an outcome or an individual's experience were included. In addition, studies reporting the following outcomes were also included cognitive health, confidence, mental health, happiness, emotional health and quality of life.

Study Design – A wide range of study designs were eligible including intervention studies (Randomised controlled trials (RCT), nonrandomised controlled trials, pre and post-test intervention studies), observational studies (including case control, cohort or survey data) and qualitative studies (including focus groups, individual interviews). In addition, any previous systematic reviews or syntheses were also considered.

Search Strategy

In order to inform this systematic review, the following search procedures were undertaken. First, an electronic database search of Embase (1974 to 2017 Week 07), PsycINFO (1806 to February Week 2 2017), Social Policy and Practice (inception to 18.2.2017) and Ovid MEDLINE (Inception to 18.2017) was undertaken. The electronic database search was undertaken using the following key word search terms (swim* or swimming pool or aquatic therapy) and (wellbeing or mental health or confidence or cognition or cerebral palsy or dementia or disability). Second, the database Google Scholar was searched on 18.2.2017 using various combinations of key search terms to identify specific articles potentially meeting the inclusion criteria. Third, combinations of key search terms were used in the main Google search database to identify nonacademic literature of potential relevance (e.g. policies). Finally, the reference lists of included articles was undertaken to identify articles that meet the inclusion criteria.

Study Selection

All 'hits' from the searches were exported into an excel file. One author (BS) reviewed the abstracts and titles of all hits and then developed a list of potentially eligible articles that were considered at the full text review. At the full text review, the eligibility criteria were applied and a final list of included studies was considered to inform the review.

Data extraction

Data or qualitative quotations were extracted on a predetermined database.

Synthesis of results

Due to the anticipated heterogeneity in terms of study deign, populations and outcomes, a quantitative synthesis (e.g. meta-analysis) was not deemed appropriate. Therefore, a best evidence synthesis was undertaken to address the questions of the review.

Search results

The initial database search acquired 5,545 potentially eligible articles. After the removal of duplicates, 4352 articles were screened at the abstract and title level.

Reference

1. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Clinical Trials. 2009;6(7):1-6.

Chapter 3

The physiological effects of swimming: a systematic review

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Key words:

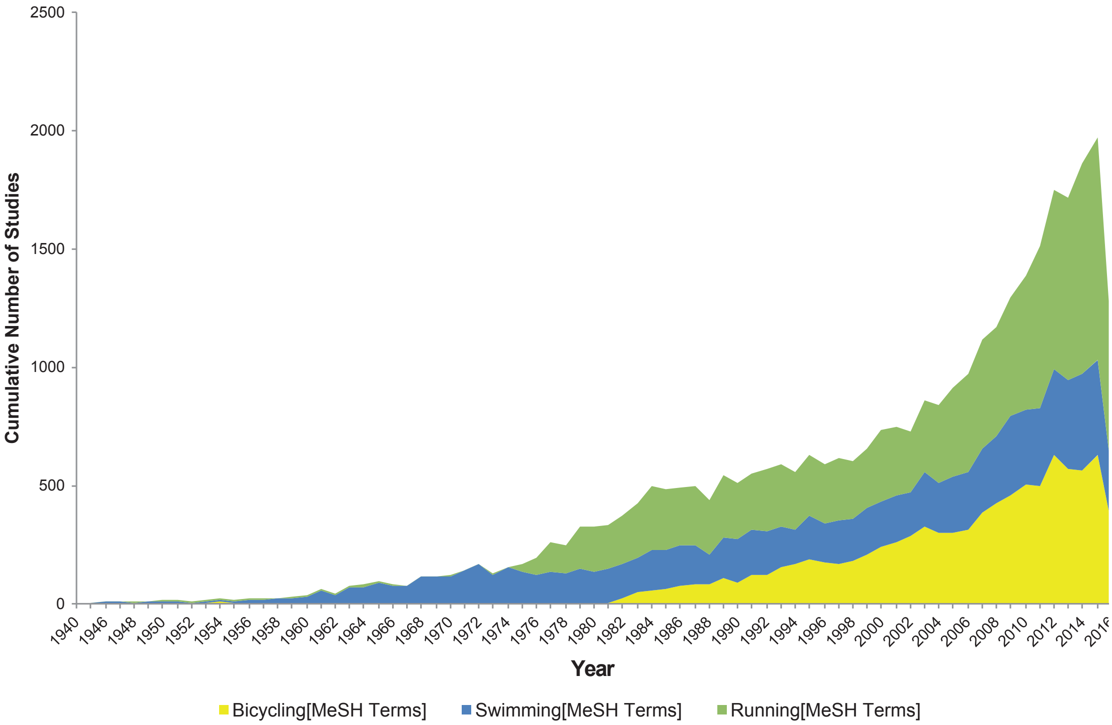
swimming
physiology
acute effects
chronic adaptations

Introduction

Regular exercise is associated with a lower risk of premature mortality and chronic disease, improved physical fitness levels, and enhanced health and quality of life (Booth et al., 2012, Warburton et al., 2006). As well as being an important life-saving skill, swimming is a popular aerobic exercise that might provide health benefits for young and adult populations, as well as patients with non-communicable disease (Chase et al., 2008). Around 14 million Americans report that they swim for fitness between one and 49 times per year, and 7.5 million swim 50 or more times a year (P.A.C., 2013). In 11 of 12 European countries surveyed, swimming was in the top five most participated in sports (Scheerder et al., 2011). According to Sport England's Active Lives Survey (A.L.S., 2016), 11% of adult respondents aged 16 years and over reported participating in swimming at least twice over a 28 day period. This survey ranked swimming as the sixth most popular activity, behind walking (73%), running (15%), cycling (15%), fitness classes (14%), and gym sessions (12%).

Swimming represents an appealing alternative form of health-enhancing aerobic exercise, especially for elderly populations and patients with chronic diseases, such as arthritis, due to its low impact nature (Lazar et al., 2013). However, despite its popularity and potential for benefit, swimming has received much less attention in the scientific literature compared to running and cycling, particularly in recent times (see figure 1). This relative under-researching of swimming can be attributed to the difficulty in taking physiological measures during swimming, the need to acquire a certain level of skill and technique to achieve a prescribed exercise intensity, and concerns over the safety of swimming for populations with non-comunicable disease (Tanaka, 2009).

Figure 1.
The number of published studies per year on bicycling, swimming, and running from 1940 to 2016 (searched for using MESH term on PubMed: 1st April 2017)



Swimming is unique from other forms of exercise regarding body position, breathing pattern, the muscles groups employed, and the medium in which it is performed. Water has several distinctive physical properties that considerably influence aquatic locomotion. These properties, such as density, pressure, and heat capacity, can therefore, determine the physiological responses and adaptations to swimming. The density of water (mass per unit volume of water), which is about 800 times greater than air (998.2 vs 1.205 kg·m^{-3} at 20°C and 760 mmHg), provides a considerable resistance to the ability of a swimmer to move through it (i.e. drag) (di Prampero, 1986). In addition, water density is influenced by its temperature. As water temperature rises above 0°C, the density of water increases until reaching a peak density of ~1 g·cm^{-3} at 4°C (the temperature of arctic water) (Pendergast et al., 2015). As the temperature of water increases beyond this point, the density of water falls in a linear fashion. The higher the density of water, the more difficult it becomes to function in water, or in other words, the higher the energy cost of swimming (Pendergast et al., 2015).

Water density also influences swimmers buoyancy (ability to float). A human's body density is slightly greater than the density of water, so when fully immersed in water the individual tends to sink (Holmer, 1979). It is therefore, easier to float in warmer water compared to colder water due to its lower density. The salt content of water also influences its density, with higher salt content increasing the mass of water, which results in a greater water density. Therefore, whereas it might be easier to float, swimming in saltwater has a greater energy cost due to its higher density compared to fresh water (Pendergast et al., 2015). Conversely, because warm water is less dense the energy cost of swimming is lower but buoyancy is reduced. However, swimmers with higher adiposity will have improved buoyancy because adipose tissue is less dense than lean tissue (di Prampero, 1986). Women tend to have a higher proportion of adipose tissue than men and therefore, sink less than men (Holmér, 1992). In addition, the lower density of women's legs allows them to swim higher in the water, reducing the drag on the body (Zamparo et al., 2011).

Water pressure becomes a crucial factor when functioning at depths starting at 10m below sea level (i.e., 2 atmosphere absolutes, where sea level pressure is 1 atmosphere absolute) (Pendergast et al., 2015). On the surface whilst swimming the pressure of water (assumed to be 40–60 mmHg) leads small respiratory and circulatory adjustments, such as compression of superficial veins, especially of the lower extremities and abdomen, resulting in a reallocation in blood volume to the thoracic cavity and heart (Meyer, 2006).

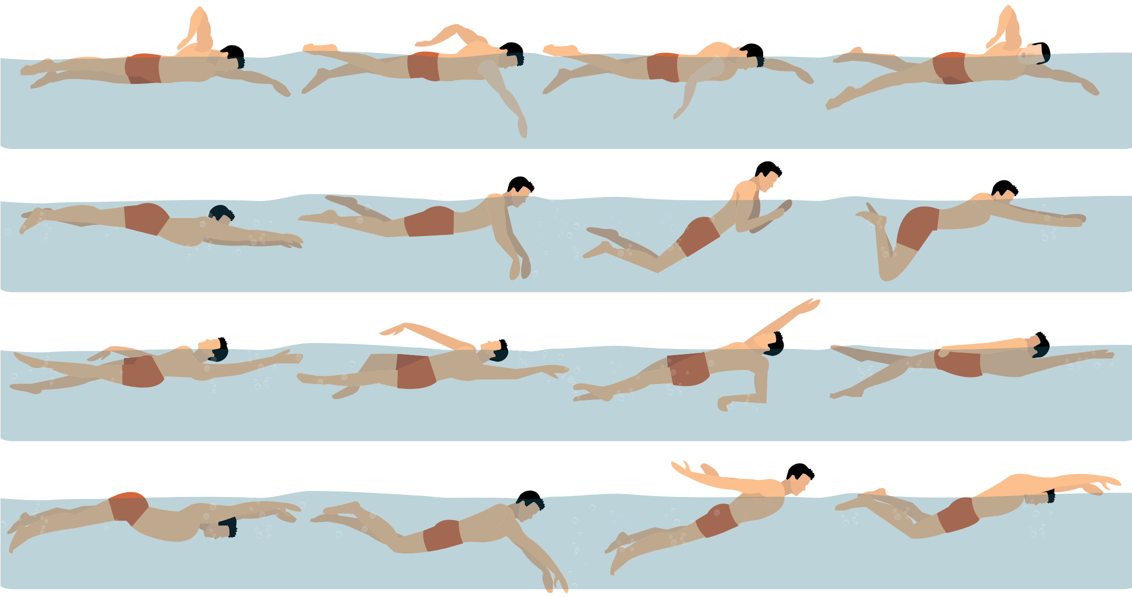
Water has a high specific heat capacity (energy required to raise temperature of pure water by 1°C = 4.18 $kJ{\cdot}kg^{-1}{\cdot}°C^{-1}$ vs. air = 1.3 $kJ{\cdot}kg^{-1}{\cdot}°C^{-1}$) and can conduct heat 20 times greater than air. The high heat conductivity of water can lead to marked increases in heat dissipation during swimming, and can have a major influence on swimming performance (Pendergast et al., 2015). Although, in waters 24-25°C enough heat can normally be produced through muscle activity during swimming to balance heat loss, further decreases or increases in water temperature can lead to an increased risk of hypothermia and hyperthermia, respectively (Holmer, 1979). The risk of hypothermia is greater in less-trained, lean men compared to both less-trained men with greater adiposity, due to the insulating properties of adipose tissue, and well-trained, lean men, due to a greater thermoregulatory capacity in trained swimmers (Holmer, 1979, Rust et al., 2012). Taken together and alone, the physical properties of water including its density, pressure, and thermal capacity and conductivity, represent significant challenges to the human swimmer and elicit particular physiological effects in an attempt to meet these demands.

Determination of the acute physiological effects of exercise is necessary to elucidate the biologic mechanisms by which repeated exposure to these effects may induce chronic adaptations. Within an evidence-based framework, knowledge of the short and long-term physiological responses to a particular exercise (e.g. swimming) is crucial to optimise the design and application of safe and effective exercise prescription (Bufford et al 2013). Furthermore, a greater understanding of swimming physiology would allow clinicians to identify the populations that may benefit most from swimming and those for which this particular mode of exercise might be contraindicated or require certain modifications or supervision to ensure safety.

Previous reviews of the physiology of swimming have focused more on competitive swimming (Aspenes and Karlsen, 2012, Barbosa et al., 2010, Cooper et al., 2007, Costa et al., 2012, Ferreira et al., 2016, Holmer, 1979, Holmér, 1992, Lavoie and Montpetit, 1986, Marino, 1984, Palayo et al., 2007, Pendergast et al., 2015, Toubekis and Tokmakidis, 2013, Troup, 1999, Videler and Nolet, 1990), with less scientific attention on swimming in healthy or chronic disease populations. Most of the reviews dedicated to the latter, have centred on the effects of swimming on cardiovascular physiology (Koenig et al., 2014, Lazar et al., 2013, Tanaka, 2009) or respiratory and asthma-related conditions (Bar-Or and Inbar, 1992, Beggs et al., 2013, Bougault and Boulet, 2012, Bougault et al., 2009, Fisk et al., 2010, Geiger and Henschke, 2015, Rosimini, 2003, Weisgerber et al., 2003). However, to the best of our knowledge, this chapter is the first to systematically review the literature examining the short and long-term physiological effects of recreational swimming in both healthy populations and those at risk of or diagnosed with chronic disease.

The current chapter consists of a synthesis of findings following the screening of 6,219 articles derived from a comprehensive literature search of the three major electronic databases (CENTRAL, PubMed, and Embase) and reference checking of eligible articles and relevant previous reviews (see Appendix A and B). The aim of the current study was to systematically review the existing literature investigating: 1) the acute physiological effects of a swimming bout, and 2) the chronic adaptations to regular swimming in young people, adults and older adults who are healthy (but not trained or swimming competitively), and populations at risk of or diagnosed with chronic disease. Only randomised controlled trials (RCT), quasi-RCT, controlled trials (CT), or pre-post design single group studies that investigated the acute and chronic physiological effects in participants who were swimming naïve, untrained or who swam recreationally, were eligible. Studies were included if they investigated the acute effects of and chronic adaptations to any of the four contemporary swim strokes, namely, front crawl, backstroke, breaststroke, and butterfly (see Figure 2). The scope of the review was to provide a physiological analysis of the effects of swimming as opposed to only immersion in water (for an excellent comprehensive review of head-out-of-water immersion interested readers are directed to Pendergast et al. 2015). In addition, due to the influence of water temperature on human physiology, the acute and chronic responses to cold water swimming [defined as swimming when air and water temperatures are below 18ºC (Kolettis and Kolettis, 2003)] are described separately. In the chapter's final section we include a summary of the key conclusions and recommendations, and consider the gaps in the knowledge base of the physiology of swimming. For a full description of the systematic review methodology and flow of studies please see Appendix A and B.

Figure 2.
Contemporary swim strokes (from top to bottom; front crawl, breaststroke, backstroke, and butterfly)



Acute Physiological Effects of Pool Swimming

Our systematic search identified 22 eligible studies (1 RCT, 2 CTs, 8 CTs with crossover, 4 pre-post single group studies, and 7 pre-post single group studies with crossover) that investigated the acute effects of swimming on different physiological responses in healthy children and adolescents (3 studies), healthy adults (9 studies), pregnant women (3 studies), and patients with cardiovascular disease (7 studies). Only one of the trials had multiple publications (McMurray et al., 1991). The eligible studies included a total of 431 participants, and all participants took part in one or more acute swimming bouts. Seven studies (n participants = 204 compared acute responses to swimming compared to cycling exercise (Bucking and Krey, 1986, Heigenhausen et al., 1977, Holmer, 1972, Lehmann and Samek, 1990, Madger et al., 1981, McMurray et al., 1991, Meyer and Buking, 2004, Lakin et al., 2013, Spinnewijn et al., 1996), whereas, three studies compared swimming to running (Dixon and Faulkner, 1975, Holmer, 1972, Holmer and Bergh 1974, n = 12), and one study each compared swimming to dance (Atsumi et al., 2008, n = 37), gymnastics (Schmid et al., 2007, n = 30), and walking, volleyball, and calisthenics (Fletcher et al., 1979, n = 22).

Eight of the eligible studies studied the acute effects of breaststroke swimming only (Böning et al., 1988, Galbo et al., 1979, Lehmann and Samek, 1990, Madger et al., 1981, McMurray et al., 1991, Spinnewijn et al., 1996, Ueda and Kurokawa, 1995, Weiss et al., 1988), two studies examined front crawl swimming only (Dixon and Faulkner, 1975, Fletcher et al., 1979), whereas, one study each included an acute bout of backstroke (Viti et al., 1989) and backstroke or breaststroke (Holmer 1972), and another study participants chose to use front crawl, breaststroke, or side stroke (Heigenhauser et al., 1977). The remaining nine studies did not provide swimming stroke information. Six eligible studies examined the acute effects of swim bouts with durations between 30 and 60 minutes (Atsumi et al., 2008; Boning et al., 1988, Galbo et al., 1979, Morgan and Shenoi, 1989, Lakin et al., 1979, Sasaki et al., 1993), whereas, 13 studies included swim bouts less than 30 seconds duration (Bucking and Krey, 1986, Dixon and Faulkner, 1975, Fletcher et al., 1979, Heigenhausen et al., 1977, Holmer, 1972, Holmer and Bergh 1974, Lehmann and Samek, 1990, Madger et al., 1981, Meyer and Buking, 2004, Schmid et al., 2007, Ueda and Kurokawa, 1995, Viti et al., 1989, Weiss et al., 1988), and the remaining three studies did not report swim duration information. The specific study characteristics as well as the outcomes of these studies appear in Table 1.

The following section will review the evidence of the acute physiological effects of bouts of swimming in each of the populations listed above and provide a summary of the risk of bias within each eligible trial. In regards to the risk, due to the nature of swimming as an intervention, participants and study personnel cannot be blinded to the type of exercise performed, and as a result all of the studies were at a high risk of performance and detection bias. In addition, because none of the studies protocols were published or registered on a trial registry, it was not possible to assess reporting bias and therefore, all eligible studies were at an unclear risk of reporting bias (see Figure 3 and Appendix D). Therefore, in each of the following populations, the only the risk of selection and attrition bias, along with other sources of bias in the eligible studies, will be summarised.

Healthy children and adolescents

Only three eligible studies (2 CTs and 1 RCT) investigated the effects of an acute bout of swimming in school children (Atsumi et al., 2008, Grace et al., 1987, Morgan and Shenoi, 1989). None of the studies provided information regarding the swim stroke adopted in swimming bouts. Two of the studies (Grace et al., 1989, Morgan and Shenoi 1989) included only measures of middle ear function. Given that chlorinated water has been identified as a risk factor for middle ear effusion (fluid build-up in middle ear), which in turn is a risk factor for hearing damage, Morgan and Shenoi (1989) investigated the acute effects of swimming on Eustachian tube function of 30 children aged between four and eight years with healthy middle ears (Morgan and Shenoi, 1989). Standard tympanometry assessments prior to swimming, 30-45 minutes after swimming and 14 hours post swimming revealed that swimming did not affect Eustachian tube function of children. Similarly, Grace and colleagues found that middle ear pressure was not adversely affected in 52 healthy schoolchildren who completed an average of four swim bouts (Grace et al., 1987). Characteristics of studies can be found in Table 1.

In the third eligible study, reported solely on free radical scavenging activity in a sample of children and adolescents (mean age: 11.8 years) (Atsumi et al., 2008). The authors (2008) found that free radical scavenging activity was significantly reduced after 50 minutes of swimming compared to resting levels, suggesting that, similar to other forms of exercise, swimming acutely reduces anti-oxidative capacity due to the production of free radicals/reactive oxygen species during exercise (Atsumi et al., 2008).

Two of the studies were at a high risk of selection bias because they were non-randomised controlled trials (Atsumi et al., 2008, Grace et al., 1987), whereas, the other study was at an unclear risk of selection bias because the authors did not provide information regarding the randomisation method used (Morgan and Shenoi, 1989) (see Figure 3 and Appendix D). All three studies were at a low risk of attrition bias because all participants completed each of the assessments. None of the studies compared the responses to swimming versus other modes of exercise in a crossover design. We found no data on the cardiorespiratory responses to swimming. Therefore, future studies are required to investigate the comparative physiological responses to swimming compared to other modes of exercise in crossover design studies (with randomised order of condition) in a sufficient number of children.

Healthy university students and adults

Nine eligible studies (3 single group studies, 2 single group studies with crossover, and 4 CT with crossover) investigated the acute effects of swimming on healthy adults (Böning et al., 1988, Dixon and Faulkner, 1975, Galbo et al., 1979, Holmer, 1972, Holmer and Bergh 1974, Lakin et al., 2013, Ueda and Kurokawa, 1995, Viti et al., 1989, Weiss et al., 1988). The duration of the single bout of exercise also varied considerably from one hour (Galbo et al., 1979, Böning et al., 1988) to a 5-8 minutes swimming test (Holmer and Bergh 1974). The majority of these studies investigated the effects of breaststroke swimming (Böning et al., 1988, Galbo et al., 1979, Holmer, 1972, Ueda and

Kurokawa, 1995, Weiss et al., 1988), whereas, two studies employed backstroke (Holmer, 1972, Viti et al., 1989), one study used front crawl (Dixon and Faulkner, 1975), and two studies did not report the swim stroke used (Holmer and Bergh 1974, Lakin et al., 2013). See Table 1 for characteristics of studies.

Three studies have reported 19-25% lower maximal oxygen uptake (VO_2max) values during swimming tests compared to running tests (Dixon and Faulkner, 1975, Holmer, 1972, Holmer and Bergh 1974), whereas, one study reported 10% lower swimming VO_2max values compared to cycling in four participants who were not "swim trained" (Holmer 1972). Similarly, swimming peak minute ventilation (VEpeak) values were approximately 15% lower compared to running (Dixon and Faulkner, 1975, Holmer 1972), and 5% lower compared to cycling (Holmer 1972). During swimming, VO_2, heart rate (HR), and blood lactate all increase progressively with increases in swimming intensity in both males and females (Ueda and Kurokawa, 1995, Weiss et al., 1988), whereas, VO_2 and blood lactate are significantly lower and HR is significantly higher while swimming in swimming pools with higher temperatures (33°C) compared to normal (27°C) or lower (21°C) swimming pool temperatures (Galbo et al., 1979).

When comparing physiological responses of swimming to cycling, HR elevates similarly in both exercise modes at submaximal and maximal intensities and it's higher when swimming whole body breaststroke versus leg or arms only (Weiss et al., 1988). However, in one study of six recreational swimmers, HRmax values were similar in four participants during swimming, running, and cycling (Dixon and Faulkner, 1975). In the same study (1975) swimming cardiac output was 25% lower compared to running, although, arterial-venous oxygen difference did not differ between the two modes. With regards to blood pressure (BP), systolic BP (SBP) also demonstrates significant progressive increases from rest (134±12 mmHg) to sub-maximal (176±22 mmHg) and maximal (187±18 mmHg) intensity (Weiss et al., 1988).

Upon the cessation of a single bout of swimming, HR and blood lactate may remain significantly elevated up to two hours post swimming in healthy untrained individuals (Viti et al., 1989, Böning et al., 1988). However, the differences in maximal lactate concentrations between swimming, cycling, and running appears to vary among individuals (Holmer 1972). Moreover, SBP remained significantly higher only within the first minute post-cycling compared to post-swimming in untrained participants, while diastolic BP (DBP) is significantly higher after cycling versus swimming up to five minutes (Lakin et al., 2013). After these immediate post-swimming BP responses, both SBP and DBP significantly reduced thereafter up to 50 minutes of recovery, whereas DBP continues to remain decreased after 75 minutes of swimming (Lakin et al., 2013). In the same study, no significant differences were observed in cardiac output, total peripheral resistance and heart rate variability during recovery between cycling and swimming, however, stroke volume was significantly lower post-swimming compared to post-cycling (Lakin et al., 2013).

Breaststroke swimming has been observed to significantly reduce plasma insulin, but not glucose (Galbo et al., 1979). The same study reported significantly decreased free-fatty acids and glycerol within 15 minutes of swimming, but progressive and significant increases from the 15th to the 60th minute (Galbo et al., 1979). In addition, different hormonal responses have been observed while swimming at different temperatures or while swimming whole body compared to legs or arms only. In specific, epinephrine and norepinephrine increased proportionately with swimming intensity and are also elevated while swimming whole body breaststroke vs. arms or legs only (Weiss et al., 1988). In addition, in healthy men, adrenaline and noradrenaline were significantly higher while swimming at lower (21°C) and higher (33°C) than normal swimming pool temperatures (Galbo et al., 1979). In healthy male university students, cortisol significantly increased only with whole body high-intensity swimming (Weiss et al., 1988) and also elevated significantly more rapidly while swimming at 33°C compared to normal swimming pool temperature i.e. 27°C (Galbo et al., 1979).

In regards to other outcomes, adrenaline, noradrenaline atrial natriuretic peptide, plasma renin and aldosterone remained significantly elevated post-swimming, irrespective of pool temperature (Galbo et al., 1979, Viti et al., 1989), however, arginine vasopressin did not change post-swimming compared to resting values (Viti et al., 1989). Finally, after swimming for 30 minutes, core temperature remained significantly reduced up to six minutes post-swimming in untrained individuals (Lakin et al., 2013).

The evidence reported above comes from small sample studies (largest study n = 17 eligible participants) with a high risk of selective bias due to a lack of random allocation to groups or randomisation of condition order (see Figure 3 and Appendix D). Three of the studies (Böning et al., 1988, Ueda and Kurokawa, 1995, Viti et al., 1989) were also at a high risk of other bias due to the single group pre-posttest design. However, all nine studies were at a low risk of attrition bias because all participants completed each of the assessments. There is a lack of studies investigating the acute effects of different swim strokes, front crawl in particular, compared to other popular modes of exercise, in crossover design studies with adequate sample sizes that randomise condition order, and blinds outcome assessors to the purpose of the experiment (e.g., independent outcome assessors for each of the conditions).

Pregnancy

Three studies have investigated the acute effects of swimming on different cardiorespiratory and metabolic maternal and/or fetal responses in women who were pregnant (McMurray et al., 1991, Sasaki et al., 1993, Spinnewijn et al., 1996). All three were small single group studies (n participants ≤17), of which two had a crossover design where all participants competed a bout of cycling in addition to a swimming bout (McMurray et al., 1991, Spinnewijn et al., 1996). Two studies (McMurray et al., 1991, Spinnewijn et al., 1996) utilized breaststroke swimming, based on an assumption that this stroke is safer for pregnant women, whereas, the other study did not report the swim stroke employed. Characteristics of studies can be found in Table 1.

Two studies assess gas exchange variables during swimming and cycling (McMurray et al., 1991, Spinnewijn et al., 1996). One study observed that, whereas swimming and cycling VO_2peak were similar 8-12 weeks postpartum, during pregnancy (25th and 35th weeks gestation) swimming VO_2peak was significantly reduced (25.5±6.2 vs. 20.8±4.4 $ml \cdot kg^{-1} \cdot min^{-1}$) but cycling VO_2peak remained unaffected (McMurray et al., 1991). The authors (1991) reported that the reduction in swimming VO_2peak was significantly correlated with decreases in VEpeak. However, Spinnewijn and colleagues (1996) found that both swimming and cycling VO_2peak was unaffected by pregnancy with similar values during pregnancy (between weeks 30-34 gestation only) and postpartum. Although, in agreement with McMurray et al. (1991), the VO_2peak was lower (~9%) for swimming compared to cycling both during and after pregnancy (Spinnewijn et al., 1996). Differences between the two above studies are likely due to the swimming test protocols employed, with one using a continuous protocol (Spinnewijn et al., 1996) and the other study utilising a discontinuous protocol (McMurray et al., 1991).

Compared to postpartum, resting HR is higher during pregnancy (McMurray et al., 1991, Spinnewijn et al., 1996). The HRmax response during pregnancy does not appear to differ between swimming and cycling (mean range: 179 to 184 bpm) (McMurray et al., 1991, Spinnewijn et al., 1996). In regards to fetal HR, in one single group study of 11 pregnant women during their third trimester (35-38th week), fetal HR rose significantly during swimming, but no pathological deceleration was observed (Sasaki et al., 1993). However, another study reported two episodes (4% of all exercise trials) of transient fetal bradycardia during maximal maternal swimming compared to four episodes (9% of all trials) during maximal cycling in a sample of 13 pregnant women at 25 and 35 weeks gestation (McMurray et al., 1991). In addition, this study (1991) also observed no significant differences in the mean umbilical artery SBP/DBP ratio observed between swimming and cycling, after adjustment for fetal HR. The results above suggest that swimming is a safe mode of exercise during pregnancy.

One of the studies also reported that both swimming and cycling resulted in significant increases in hematocrit, hemoglobin and total plasma protein, however, all variables were significantly lower during pregnancy compared to postpartum (McMurray et al., 1991). Only one study reported blood lactate responses, and found that blood lactate was lower during pregnancy versus postpartum and compared to cycling (Spinnewijn et al., 1996).

The generalisability of the above findings is difficult due to the small number of studies with low samples sizes. Breaststroke was the only reported stroke studied in the above studies, so results are confined to this stroke. In addition, none of the two crossover studies (McMurray et al., 1991, Spinnewijn et al., 1996) randomised the order in which the swimming and cycling bouts was performed resulting in a high risk of selection of bias (see Figure 3 and Appendix D). These same two trials also excluded participants who did not complete all assessments leading to a high risk of attrition bias. Sasaki et al. (1993) was also at a risk of other bias due to the single group pre-post test design. Therefore, there is need for crossover design studies with adequate sample sizes that randomise condition order, adopts an intention-to-treat analysis approach, and blinds outcome assessors to the purpose of the experiment, that investigate acute responses to swimming before, during, and after pregnancy compared to different modes of exercise.

Individuals with cardiovascular disease

Studies have also focused on the acute physiological effects of swimming in individuals with different cardiovascular diseases. We identified three single group with crossover studies (Bucking and Krey 1986, Fletcher et al., 1979, Madger et al., 1981) and four CTs with crossover (Heigenhausen et al., 1977, Lehmann and Samek, 1990, Meyer and Bucking 2004, Schmid et al., 2007). In general, the physiological effects of swimming were investigated after swimming bouts of various durations, from five minutes of comfortable swimming (Bucking and Krey 1986, Meyer and Bucking, 2004) to swimming 100 feet (Fletcher et al., 1979), and intensities, from incremental intensity or comfortable speed swimming tests (Heigenhausen et al., 1977, Madger et al., 1981, Schmid et al., 2007) to intermittent swimming protocols (Lehmann and Samek, 1990). In three studies the style of swimming was breaststroke (Lehmann and Samek, 1990, Madger et al., 1981, Meyer and Bucking 2004), in two studies stroke was not provided (Schmid et al., 2007, Bucking and Krey 1986), one study used front crawl (Fletcher et al., 1979) and in one study the participants chose their own stroke (front crawl, breaststroke, or side stroke) (Heigenhausen et al., 1977). Characteristics of studies can be found in Table 1.

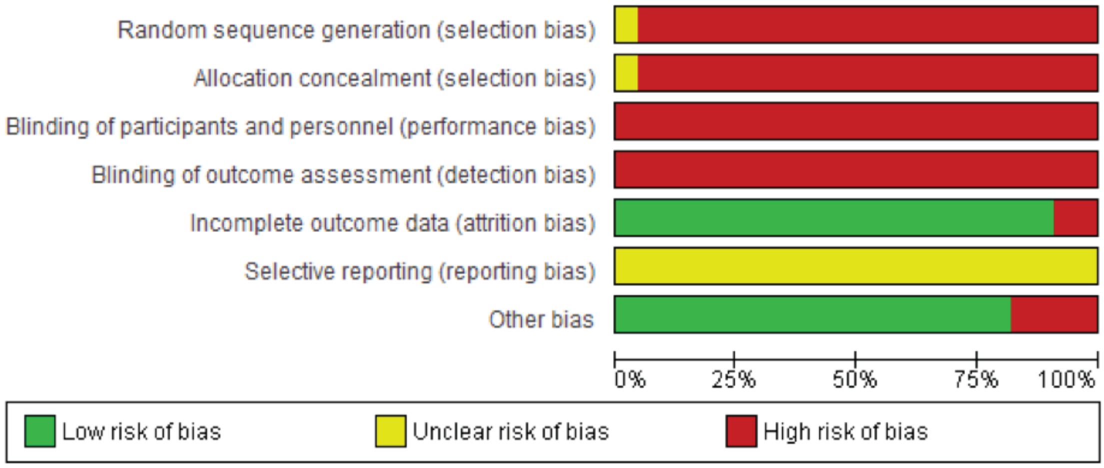
During swimming, there was a linear increase in VO_2, which was proportionate to increases in intensity in males with previous myocardial infarction (MI) (Heigenhausen et al., 1977). In another study, the VO_2 response during swimming was lowest in patients with chronic heart failure (9.7±3.3 $ml·kg^{-1}·min^{-1}$) compared to patients with coronary artery disease (12.4±3.5 $ml·kg^{-1}·min^{-1}$) and healthy controls (13.9±4 $ml·kg^{-1}·min^{-1}$) (Schmid et al., 2007). While similar increases in VO_2 were observed between swimming and cycling in two studies (Heigenhausen et al., 1977, Madger et al., 1981), VO_2 during swimming was higher when compared to other exercise modes, such as walking and playing volleyball in untrained individuals post uncomplicated MI (Fletcher et al., 1979). For patients with ischemic heart disease, swimming at individual-selected comfortable speeds required 81±16% at 25.5°C and 83±17% at 18°C of VO_2peak (Madger et al., 1981). However, the authors (1981) reported that VO_2 response varied greatly dependent on swimming ability, with the worst swimmer consuming as much as 108% (VO_2 = 1.47 L·min) of VO_2peak achieved during cycling, compared to the best swimmer who used as 54% (VO_2 = 0.85 L·min) of cycling VO_2peak (Madger et al., 1981). Furthermore, Heigenhauser and colleagues (1977) reported that in patient's post MI, VO_2peak was 21% lower during swimming compared to cycling, despite higher HR at any given VO_2, possibly due to a potential failure of participants to reach maximal values.

HR and cardiac output (CO) also increased proportionately to intensity (Heigenhausen et al., 1977, Schmid et al., 2007) with similar responses occurring during swimming and cycling (Heigenhausen et al., 1977, Meyer and Bucking 2004, Madger et al., 1981), but higher HR during swimming compared to walking and playing volleyball in individuals post MI (Fletcher et al., 1979). Significantly higher HR and lower CO at any given VO_2 have also been reported in individuals post MI (Heigenhausen et al., 1977). During swimming, SBP increased to 122, 143 and 130 mmHg in healthy individuals, patients with coronary artery disease and chronic heart failure, respectively, whereas, SBP and DBP also increased significantly more in patients with coronary artery disease compared to patients with chronic heart failure and healthy individuals (Schmid et al., 2007). Furthermore, immediately post-swimming and up to 95 minutes recovery, CO, total peripheral resistance and respiratory frequency were unchanged compared to baseline values in patients with coronary artery disease and chronic heart failure (Schmid et al., 2007). Finally, in a study of four heart disease patients 6-10 weeks post-MI, compared to after five minutes of cycle ergometry at 100 W, higher mean pulmonary arterial and pulmonary capillary pressures and oxygen saturation, but not HR, were observed after five minutes of swimming at a speed of 20-25 $m·min^{-1}$ (Bucking and Krey, 1986).

With regards to adverse cardiac physiological responses of swimming, a study of four patients with previous transmural infract, found no arrhythmias during swimming (Bucking and Krey 1986). While this was also the case for 13 patients with coronary artery disease and mild left ventricular damage, three out of 12 patients with coronary artery disease and marked left ventricular damage experienced arrhythmias while swimming (Lehmann and Samek, 1990). There is a suggestion that patients who were post-MI are less able to identify ischemic symptoms during swimming. In a study that included eight post-MI patients that experienced ST segment depression and angina at their post-MI exercise tolerance test, six of these participants had ST segment depression both at swimming pool temperatures of 25.5ºC and 18ºC while swimming, two had angina in 25.5ºC and only one at 18ºC (compared to 5 participants reporting angina during cycling) (Madger et al., 1981).

When interpreting the above findings, it is important to note that three of the seven studies (Bucking and Krey 1986, Madger et al., 1981, Heigenhausen et al., 1977) had very low sample sizes (n = 4-12), which limits generalisability. The swim bouts (mostly breaststroke or frontcrawl) studied were also of very short duration (all <10 minutes), with two of the trials using bout durations of 1-2 minutes (Fletcher et al., 1979, Schmid et al., 2007). All studies were at a high risk of selection bias due to a lack of randomisation of either group allocation or condition order, but a low risk of attrition bias, because of acceptable handling of missing data (or no reported missing data) and other sources of bias (see Figure 3 and Appendix D). Therefore, appropriately designed crossover studies using longer duration bouts of swimming with larger samples are required to establish the acute effects and suitability of swimming in patients with cardiovascular disease, compared to other exercise modes used during rehabilitation.

Figure 3.
Risk of bias of acute swimming studies. Review authors' judgements about each risk of bias item presented as percentages across all included studies.



Chronic Physiological Adaptations to Pool Swimming

Our systematic search on the chronic physiological adaptations of swimming revealed 31 eligible trials (16 RCTs, 2 quasi-RCT, 11 CTs, and 2 single-group studies) investigating the effects of swimming on physiological outcomes in healthy children and adolescents (3 studies), university-aged students and adults (7 studies), as well as pregnant women (1 study) and individuals with asthma (11 studies), down-syndrome (1 study), cystic fibrosis (1 study), hypertension (5 studies), osteoarthritis (1 study), and perforated tympanic membrane (1 study). Seven of the trials had multiple associated publications (10 additional articles). There were a total of 1,592 participants in the eligible studies, with 886 participating in a swim training group, 476 in a non-swimming control (22 studies), 84 in a walking group (2 studies), 55 in a cycling group (3 studies), 35 in a running group (2 studies), 20 in a soccer group (1 study), and 26 in a golf group (1 study). Four of the studies compared two different swim interventions (Fernandez-Luna et al., 2013, Lavin et al., 2015, Mohr et al., 2014, Soultanakis et al., 2012), whereas in another two studies participants performing the same swim intervention were separated into groups based on condition symptoms (Bemanian et al., 2009; Fitch et al., 1976).

In 10 of the studies, the swim intervention consisted of front crawl only (Casey and Emes, 2011, Celik et al., 2013, Magel et al., 1975, Lavin et a;., 2015, Lun and Wang, 2014, Matsumoto et al., 1999, Mohr et al., 2014, Soultanakis et al., 2012, Silva et al., 2009, Tanaka et al., 1997, Varray et al., 1991), three studies used a combination of backstroke and front crawl (Wang and Hung, 2009, Weisgerber et al., 2003, Weisgerber et al., 2008), one study involved front crawl and breaststroke, one study utilised breaststroke only (Obert et al., 1996), three studies comprised of a variety of swim strokes (Bielec et al., 2013, Cox et al., 2006, Lynch et al., 2007), and the other 12 studies did not provide swim stroke information. Most of the studies were of short-durations, with the 22 studies less than 15 weeks duration (mode duration = 12 weeks in 9 studies; range = 4 weeks to 2 years). Three studies had a duration of one year (Chen et al., 2010; Huang et al., 1989, Obert et al., 1996), whereas, one single group study consisted of a 2-year intervention (Bielec et al., 2013). In the following section we will review the evidence of the effects of swim training in each of the populations listed above and provide a summary of the risk of bias within each eligible trial (see Figure 4 and Appendix E). The characteristics and the outcomes of the studies included appear in Table 2.

Healthy children and adolescents

We found just three eligible studies investigating the effects of swim training in healthy children (Gonenc et al., 2000), pre-pubertal girls (Obert et al., 1996), and adolescents (Bielec et al., 2013). Two studies were controlled trials (CTs) and one was a pre-post single group design, none of the three eligible studies were RCTs. One two year study involved a breaststroke intervention (Obert et al., 1996), whereas, another study utilised a one year intervention comprising of a mixture of front crawl, backstroke, and breast stroke (Bielec et al., 2013), and the third study compromised of a four week technical swim drill intervention (Gonenc et al., 2000). See Table 2 for the characteristics of studies.

Only one small study (Obert et al., 2016), consisting of 14 pre-pubertal girls (intervention n = 5), examined the effects of swim training (10-12 hours per week for 1 year) on VO_2peak (assessed via swim bench exercise test), and found significant pre-post increases in relative VO_2peak (ml·min^{-1}·kg^{-1}·mb). In addition, significant pre-post improvements in HRmax, VEmax (L·min^{-1}), and maximal O_2 pulse were observed in the swim group only. However, absolute VO_2peak (L·min^{-1}) changed significantly in both groups. A pre-post single group study (Gonenc et al., 2000) reported beneficial improvements in anti-oxidant defence (assessed via superoxide dismutase, malondiadehyde, and glutathione peroxidase) in 12 untrained healthy children.

Two of the CTs investigated body mass and body mass index (BMI) changes in response to swim training. Bielec and colleagues (2013) reported that in a large population of 6th grade junior high school students (n = 230) gains in body mass were significantly lower after one year in the swim group (1 x 45 minutes per week swimming) compared to controls, but not after two years. Similarly, no significant between group differences in BMI, posture scoliosis, or scapula and shoulder asymmetry were observed over the two years. Obert et al. (1996) reported significant pre-post increases in body mass and lean mass in both swim and control groups, but a significant increase in body fat % in the control group.

Importantly, all studies were at a high risk of selection bias (no randomisation or allocation concealment), performance bias (no blinding of participants or researchers to knowledge of intervention received), detection bias (outcome assessors were not blind to group allocation) (see Figure 4 and Appendix E). The three studies were also at an unclear risk of reporting bias (insufficient information about selectiveness of reporting), but a low risk of attrition bias due to no missing data. One study was judged to be at a high risk of other bias because of a pre- and post-test single group design, whereas, the other two studies were at a low risk of other sources of bias.

Due to the high risk of bias across the three studies, caution must be exercise when interpreting the findings of these studies. Therefore, there is currently insufficient evidence regarding the effects of swim training on aerobic capacity, body mass and composition, and anti-oxidant defences. Future research is needed to investigate the efficacy of swim training in healthy children and adolescents, in addition to examining the comparative effects of swim training compared to other modes of exercise.

Healthy university students and adults

Seven eligible studies (5 RCTs and 2 CT) investigated the effects of swim training on healthy university students (Celik et al., 2013, Magel et al., 1975, Lu and Wang, 2014, Soultanikis et al., 2012) and adults (Cox et al., 2006, Fernandez-Luna et al., 2013, Lavin et al., 2015). All but one of the studies were 12 weeks or less duration (Cox et al., 2006 was 6 months), and five of the seven employed a front crawl swim intervention, whereas, the remaining two used a mixture of swim strokes (Cox et al., 2006, Fernandez-Luna, 2013). See Table 2 for the characteristics of studies.

Three studies have shown increases in VO_2peak or VO_2max with a swim training intervention (Celik et al., 2013, Magel et al., 1975, Cox et al., 2006). One study observed mean pre-post increases of ~5 ml·kg^{-1}·min^{-1} mean in sedentary male university students over 12 weeks healthy adults (Celik et al., 2013), whereas, another study involving six university-aged recreational swimmers reported 11% increases in VO_2peak (Magel et al., 1975). However, Cox and colleagues (2006) revealed more modest changes relative to walking in sedentary women aged 50-70 years over six months (mean pre-post increase in predicted VO_2peak swimming vs. walking, 1.75, 95% CI, 1.27 to 2.24 ml·kg^{-1}·min^{-1} vs. 2.54, 2.00 to 3.08 ml·kg^{-1}·min^{-1}).

The pre-post changes in VO_2peak in the two studies were equivalent to changes observed in running and cycling (Celik et al., 2013) and walking (Cox et al., 2006) interventions. Interestingly, the changes in swimming VO_2peak may be specific to swimming. Magel and colleagues (1975) found no significant increases in running VO_2peak despite the improvement in swimming VO_2peak. In the same study (1975), VEmax, HRmax, and swim time also improved significantly pre-post swim intervention, with no changes in values during running or the reported pre-post values of a separate control group. No improvement in VO_2peak were observed as a result of short duration stroke-matched breathing and controlled breathing during swimming interventions (12 sessions over 4 weeks), and no changes in other submaximal exercise variables [e.g., HR, respiratory exchange ratio (RER), or rating of perceived exertion] were found (Lavin et al., 2015). However, in this study (2015), pre-post running economy improved in both swim groups, with a slightly greater increase with controlled breathing during swimming.

In a brief four week study that randomised healthy collegiate untrained swimmers into either a sprint swimming or sprint combined with endurance swim training, only the sprint and endurance swimming combined group significantly improved pre-post swimming velocity at lactate threshold (i.e., improved exercise capacity) (Soultanakis et al., 2012). Both swim groups significantly increased 50 meters swim sprint performance and peak swim velocity, and lowered lactate concentrations at lactate threshold, but neither group changed pre-post peak blood lactate concentrations or the blood lactate concentration at individual lactate threshold after four weeks (Soultanakis et al., 2012).

Only one of the eligible studies investigated the effects of swim training on BP compared to a walking intervention in heathy sedentary women aged 50-70 years (Cox et al., 2006). This large RCT (n = 116) found that six months of swim training resulted in a statistically significant 4.4 mmHg (95% CI 1.2 to 1.75 mmHg) increase in supine SBP (and standing SBP) relative to the walking group (adjusted for initial BP, age, hypertension treatment status and change in weight). No significant within-group or between-group changes in DBP were observed at 6 months. In light of the SBP increase observed with swimming compared to walking, the authors suggested that for sedentary healthy older women wishing to engage in swim training, blood pressure monitoring may be needed. However, because this study lacked a no exercise control group, it is unclear whether the changes were due to spontaneous changes in BP (due to regression to the mean). It is also noteworthy the low baseline BP values of participants in this study. Taken together, further research is required to determine the clinical significance of this finding.

Only one study, consisting of 116 sedentary older women, investigated the effects of swim training on blood biomarkers (Cox et al., 2006). This six-month RCT with a 12 month follow-up (2006), found that despite no within or between group differences in total cholesterol (TC), high-density lipoprotein cholesterol (HDL-C), low-density lipoprotein cholesterol (LDL-C), and triglycerides after 6 months of either swimming or walking, at 12 months follow-up, the walking group had significantly increased TC and LDL-C compared to the swimming group. However, no significant within or between group differences were observed for fasting glucose, glucose area under curve (AUC), fasting insulin, and Homeostasis Model Assessment, at either 6 months or 12 months, although, insulin AUC was significantly higher in the walking group at 6 months but not 12 months compared to the swim training group. The authors (2006) suggested that these positive impacts on lipids with swimming may counteract the increases in SBP reported above.

Only two of the eligible studies (Fernández-Luna et al., 2013, Lavin et al., 2015) examined the effects of swim training on lung function in healthy adults. Significant increases forced vital capacity (FVC) have been reported in healthy adults after a three month swim training intervention in both chlorinated (pre: 4.25±0.86 L; post: 4.35±0.85 L) and ozone (pre: 4.26±0.86 L; post: 4.43±0.82 L) pools, whereas, significant increases in 1-second forced expiratory volume (FEV1) were only observed in the ozone pool swim group (pre: 3.50±0.65 L; post: 3.59±0.67 L) (Fernández-Luna et al., 2013). In addition, forced expiratory flow (FEF) 25-75% decreased significantly only after swimming in the chlorinated pool, and no pre-post changes in any other pulmonary variables were observed in the control group (Fernández-Luna et al., 2013). Interestingly, the authors (2013) also found higher lung permeability (significantly higher concentrations in Clara cell secretory protein 16 but not surfactant protein) in those swimming in the chlorinated pool compared to ozone pool, suggesting that ozone pools impact less on the lung epithelial of swimmers.

Increases in FVC with relevant decreases in FEV1/FVC have also been observed in adults as a result of a stroke-matched breathing intervention (12 sessions over 4 weeks) but not controlled breathing during swimming, whereas, significant pre-post intervention increases in maximum expiratory pressure were also observed when data were pooled from both interventions (Lavin et al., 2015).

Statistically significant reductions in body mass and BMI have been observed in sedentary older healthy women after six months of swim training, and significantly lower body mass and BMI at 12 months follow-up in a swim versus walking intervention group (Cox et al., 2016). Similarly, Lu and Wang (2014) observed a significant but modest decrease in BMI after 12 week swimming, cycling, power striding, and running interventions but not in a control group. In another RCT, although, there were significant reductions in pre-post BMI of sedentary healthy male college students in swim, running, and cycling intervention groups (vs. no change in a control group), no significant reductions were also observed in any group after 12 weeks in body fat % (Celik et al., 2013). No pre-post changes in body mass and BMI were observed in after a 4-week swimming intervention of either stroke-matched breathing and or controlled breathing during swimming interventions (Lavin et al., 2015).

One study investigated the effects of swim training on various anthropometric measurements compared to walking (Cox et al., 2006). This study (2016) observed that waist circumference was significantly lower in the swim group compared to the walk group at 6 months but not at 12 months follow-up, whereas, hip circumference was significantly lower in the swim group compared to the walk group at both 6 and 12 months. In addition, pre-post 6-month arm muscle girth and 6-month and 12-month calf girth were significantly lower in the swim group compared to the control group. No between group differences were observed in any other anthropometric measure (triceps skinfold and forearm, chest, gluteal thigh, and mid-thigh girth).

In regards to other outcomes in swim training studies with health adults, no effects were detected in cartilage oligomeric matrix protein, a marker of cartilage degradation (Celik et al., 2013) or total cartilage volume (Lu and Wang, 2014). Swim training also seems to have beneficial effects in improving strength. Swimming for 12 weeks induces increases in muscular strength in male University students (Celik et al., 2013) and college students (Lu and Wang, 2014).

However, most evidence for the physiological effects of swim training in healthy university students or adults is based on short-duration (6 studies ≤12 weeks), small sample (average group size: 16) RCTs. All seven studies were at a high risk of performance and detection bias (no blinding of participants or research personnel/outcome assessors), and an unclear risk of reporting bias (lack of sufficient information to make a judgement) (see Figure 4 and Appendix E). Three trials were at a high risk of selection bias, due to a lack of random allocation of groups (Fernandez-Luna et al., 2013, Magel et al., 1975) and a failure to conceal allocation in the other (Celik et al., 2013), whereas, two studies were at an unclear risk of selection bias due to insufficient information regarding randomisation method used (Lavin et al., 2015, Soultanikis et al., 2012). All trials were considered at a low risk of attrition bias (minimal or no loss-to-follow-up) or other sources of biases. Therefore, despite the potential of swimming training to improve cardiorespiratory fitness, and modestly reduce body mass and certain girth measurements, the findings above are generally based on short-duration and small sample RCTs. Consequently, adequately powered trials investigating the effects of different swim strokes with blinded outcome assessors and better reporting of randomisation and allocation concealment methods are needed. In particular, we can provide no firm recommendations regarding the effects of swimming on lung function in healthy adults because of a lack of low bias RCTs with a non-swimming control group.

Pregnancy

We identified one eligible small sample short-duration CT that investigated the effects of swim training on different physiological parameters of pregnant women (Lynch et al., 2007). The study included 23 sedentary women that initiated swimming training (involving front crawl, backstroke, breaststroke, and skill drills) from the 16th until the 28th week of gestation (i.e. 12 week intervention) and 11 previously active non-swimming pregnant women as a control. Although the swimming program intended to cease on the 28th week of gestation, nine women continued to swim until the 32nd week of gestation and seven until the 36th week of gestation. After the 12 week intervention, aerobic fitness, assessed via physical work capacity at a HR of 170 bpm during submaximal cycle ergometer testing, improved significantly after 12 weeks (16th to 28th week: 804 kg·m·min to 898 kg·m·min) and thereafter, remained unchanged at 36 weeks of gestation (897 kg·m·min) in those women that continued. Physical work capacity of the non-swimming group remained unchanged over the study period. Resting maternal HR significantly reduced post-intervention, while, fetal heart rate also significantly decreased with advancing gestational age. However, maternal SBP, DBP and umbilical artery systolic/diastolic ratios remained unchanged. Similar gains in body mass have been reported with the progression of gestation in both swimming and control individuals. In addition, no significant differences were detected between the groups for pre-swimming and during-swimming HR or rectal temperature and body mass.

However, this study was at a high risk of bias. Specifically, there was a high risk of selection bias, due to the allocation of women based on physical activity levels (only sedentary women were allocated to the swim training group), performance bias, a result of a lack of blinding of participants and personnel, detection bias, because of a lack of blinding of outcome assessors, and attrition bias, due to the omission from the analyses of participants who dropped out of the study (see Figure 4 and Appendix E). Whereas, the study was deemed to be at a low risk of other sources of bias, there was an unclear risk of reporting bias because of insufficient information available to make a judgement. Therefore, there is a scarcity of good quality data regarding the effectiveness of swim training for women during pregnancy.

Individuals with asthma or cystic fibrosis

Ten eligible studies examined the effects of swim training in children with asthmatic, whereas, one RCT studied the effects of swimming in adults with mild but persistent asthma. Of the six studies that comprised of children with asthma, seven were RCTs (Matsumato et al., 1999, Varray et al., 1995, Varray et al., 1991, Wang and Hung, 2009, Weisgerber et al., 2003, Weisgerber et al., 2008, Wicher et al., 2010), and three were CTs (Bemanian et al., 2009; Fitch et al., 1976, Huang et al., 1989). Eight of the studies included non-swimming controls (Arandelovic et al., 2007, Huang et al., 1989, Matsumoto et al., 1999, Varray et al., 1991, Varray et al., 1995, Wang and Hung, 2009, Weisgerber et al., 2003, Wicher et al., 2010), one study compared swimming with a golf control (Weisgerber et al., 2008), one study separated the swim group into participants who were healthy, had asthma, allergic rhinitis, or atopic dermatitis (Bemanian et al., 2009), and another study included a non-asthmatic swimming comparison group (Fitch et al., 1976). Six of the studies provided no information regarding swim stroke, but of the remaining three studies, three used front crawl and backstroke (Wang and Hung, 2009, Weisgerber et al., 2003, Weisgerber et al., 2008). and two involved a front crawl only intervention (Matsumoto et al., 1999, Varray et al., 1991). See Table 2 for characteristics of studies.

Swim training significantly and meaningfully imporoved VO_2peak and ventilatory threshlold compared with usual care in two studies (Varray et al., 1995, Varray et al., 1991). Cardiorespiratory fitness, assessed via physical work capacity (treadmill running) at 170 beats per minute, improved as a result of five months of swim training in school children with asthma, but not in a non-asthmatic swimming control group (Fitch et al., 1976), and after 12 weeks of swim training in another study (Wicher et al., 2010). Children with asthma, who swam every day for six weeks, achieved a significantly higher improvement in work load at lactate threshold assessed by both swimming and cycle ergometer, compared to a non-swimming asthmatic control group (Matsumoto et al., 1999). However, no significant differences were observed between swim training and golf groups after nine weeks (Weisgerber et al., 2008).

The effects of swim training in children with asthma on spirometry variables are mixed. In a study of 96 girls who were healthy or had asthma, allergic rhinitis, or atopic dermatitis, a 2-month swim training intervention resulted in improved peak expiratory flow (PEF) rate improved by more than 20% in 27.6% of all girls (Bemanian et al., 1999). In the same study (1990), significant PEF rate pre-post increases were observed in healthy individuals, and participants who were asthmatic or obese, but not in those with rhinitis or dermatitis. Similarly, PEF improved significantly by 63% in a group of asthmatic children after one year of swimming, compared to a 25% increase in a non-swimming, age, gender, and asthma severity matched control group (Huang et al., 1989). Only PEF improved in another group of asthmatic children after six weeks of swimming (mean, 95% CI pre: 244 L·min, 228 to 260; post: 330 L·min, 309 to 351), while all other spirometry parameters (FEV1, FEF50%, FEF25-75%) significantly increased in both swimming participants and controls (Wang and Hung, 2009). In agreement, Fitch et al. (1976) also failed to show significant pre-post improvements in FEV1 and FVC after five months of swimming in schoolchildren with asthma, and three RCTs did not find any significant improvement in measures of lung function with swim training compared to usual care controls (Varray et al., 1995, Varray et al., 1991, Wicher et al., 2010). Although in one study a swim group had significant increases in FEV1 % predicted compared to a golf group (Weisgerber et al., 2008).

Exercise-induced asthma appears to remain unaltered after a 5-month swimming intervention in asthmatic children, while asthma disability and medication use significantly decreased (Fitch et al., 1976). In another study, significant reductions were recorded for asthmatic children (but not controls) in asthma attacks, wheezing, days requiring medication, hospitalization, emergency visits and absence from school as a result of a one year swimming intervention (Huang et al., 1989). However, another study found no beneficial improvements in symptoms (and respiratory function) in children with moderate persistent asthma, however, this study was of a much shorter duration (5-6 weeks) and also, lost many participants at follow up (Weisgerber et al., 2003). Swim training may also result in significant reductions in exercise-induced bronchoconstriction in asthmatic children after swimming in a heated pool (Matsumoto et al., 1999) as well as improved asthma severity (Wang and Hung, 2009) after six weeks of swimming.

There is a paucity of data regarding the effects of swim training on body mass and composition in children with asthma. Only one eligible study included body composition as an outcome variable, and reported that after a five month swimming intervention body fat % was significantly reduced compared to controls (Fitch et al., 1976).

One eligible RCT found that in adults with mild but persistent asthma, FEV1 (pre: 3.55±0.85 L; post: 3.65±0.86 L), FVC (pre: 4.27±0.97 L; post: 4.37±0.98 L) and PEF (pre: 7.08±1.87 L; post: 7.46±1.67 L) improved after 6-months of swim training in a non-chlorinated pool (swimming delivered alongside asthma education) (Arandelović et al., 2007). When the authors (2007) compared the swim training group to the control group at the end of the study, FEV1, FVC, and PEF were significantly higher in the swim training group. In addition, although there was a significant improvement in reduced bronchial hyper-responsiveness in both swim and control groups, after the study period bronchial hyper-responsiveness was significantly lower in the swim group compared to the control group (Arandelović et al., 2007).

All of the trials investigating individuals with asthma were at a high risk of performance and detection bias because of a failure to blind participants, study personnel and outcome assessors (see Figure 4 and Appendix E). Only one study was at a low risk of selection bias (Weisgerber et al., 2008). Three studies were at a high risk of selection bias, due to inadequate randomization and allocation of concealment (Bemanian et al., 2009, Fitch et al., 1976, Huang et al., 1989), and another six were at unclear risk of bias, because of insufficient information provided about randomization methods (Arandelović et al., 2007, Matsumato et al., 1999, Varray et al., 1995, Varray et al., 1991, Wang and Hung, 2009, Wicher et al., 2010). Weisberger et al. (2003) was at a high risk of selection bias due to a lack of allocation concealment, despite an acceptable randomization method (random numbers table). five studies (Arandelović et al., 2007, Huang et al., 1989, Weisgerber et al., 2003, Weisberger et al., 2008, Wicher et al., 2010) were at a high risk of attrition bias as a result of exclusion of non-completers from their analyses, whereas, all remaining studies were at a low risk. All studies were at unclear risk of reporting bias because insufficient information was available on which to base a judgement, and only one (Bemanian et al., 2009) of the seven studies were at a high risk of other sources of bias due to poor level of reporting in the trial. There is a need for well-designed RCTs with a non-swimming control with an adequate sample size of duration in children with asthma, in particular.

One study has focused on swimming and cystic fibrosis (Edlund et al., 1985). This CT investigated a 12-week progressive aerobic swimming training (no swim stroke details provided) program (swimming pool temperature at 32-35^{o}C) against a non-swimming control group. The VO_2peak (pre vs. post: 56.2±6.7 vs. 60.0±14.28 ml·kg^{-1}·min^{-1}) and VEmax (pre: 39.8±6.6 vs. post: 45.8±16.2 L·min^{-1}) both improved significantly in the swimming group but not controls, while pulmonary function (FEV1, FVC, residual volume, total lung capacity, residual volume/total lung capacity %, and diffusion capacity) did not improve in either of the groups. Importantly, the clinical disease state of these patients significantly improved in the swimming but not controls groups. However, this small trial had a number of shortcoming that exposed it to high risk of bias, including selection bias (groups were not randomly allocated), performance and detection bias (lack of blinding of participants, personnel, and outcome assessors), and attrition bias (non-completers excluded from analyses), and an unclear risk of reporting bias (insufficient information provided) (see Figure 4 and Appendix E). However, we could find no other potential sources of bias. Due to the availability of a single flawed short-duration small sample CT, no firm recommendations can be made regarding swimming for individuals with cystic fibrosis.

Individuals with hypertension

We found five eligible studies investigating the effects of swim training in individuals with hypertension. Of these studies, two CTs studied patients with either mild (stage 1) or moderate (stage 2) hypertension (Silva et al., 2009, Tanaka et al., 1997), one pre-post SG study consisted of both mild and normotensive young adults (Chen et al., 2010), one quasi-RCT included premenopausal women with mild hypertension and obesity (Mohr et al., 2014), and another quasi-RCT comprised of participants with prehypertension or mild hypertension (Nualnim et al., 2012). Three of the studies involved a front crawl intervention (Mohr et al., 2014, Silva et al., 2009, Tanaka et al., 1997), whereas, the remaining two studies did not provide this information. Table 2 provides the full characteristics of studies.

A non-significant pre-post increase in treadmill VO_2peak (28±1 to 30±1 ml·kg^{-1}·min^{-1}) of adults diagnosed with either prehypertension or mild hypertension was reported after 12 weeks of swim training at intensities equal to 60-75% of HRmax, compared to no pre-post change at all in the control group (27±1 ml·kg^{-1}·min^{-1} before and after) (Nualnim et al., 2012). Another study of women with mild hypertension and obesity found that pre-post endurance performance (via Yo-Yo Intermittent Endurance test) was improved equivalently in both a moderate- and high-intensity swim intervention (45±4% and 58±5%), with no changes in a control group (Mohr et al., 2014). In the same study, the HR response to submaximal exercise was significantly similarly reduced before and after both moderate and high-intensity swim training. Tanaka and colleagues (1997) assessed exercise capacity via blood lactate concentrations during submaximal exercise, and found significantly decreased blood lactate concentrations after the same submaximal test pre and post a 10-week swim intervention (pre: 3.1±0.5 vs. post: 2.6±0.2 mmol·L) in patients with hypertension (Tanaka et al., 1997).

Four of the eligible studies consisting of individuals with hypertension have found reductions in SBP (Chen et al., 2010, Mohr et al., 2014, Nualnim et al., 2012, Tanaka et al., 1997), whereas in contrast, two studies found increases after swim training (Chen et al., 2010, Silva et al., 2006). In women who were hypertensive and obese, SBP significantly decreased 15-weeks post-swimming intervention both with high-intensity (mean: -6±1 mmHg) as well as moderate-intensity (mean: -4±1 mmHg) swim training with no significant changes in DBP (Mohr et al., 2014). Similarly, significant reductions in seated and supine SBP (but not DBP) were observed 10-weeks post swimming intervention (seated SBP pre-post: 150±5 to 144±4 mmHg) in individuals with mild and moderate hypertension (Tanaka et al., 1997). In addition to significant pre-post reductions in casual SBP (131±3 to 122±4 mmHg), Nualnim et al. (2012) also reported significant decreases in ambulatory SBP and carotid SBP in a swim training group, with no significant changes found in an attention control group. These findings are consistent with a single group design study which demonstrated that a one year swim training significantly lowered resting SBP by ~17 mmHg in young adults with mild hypertension (n = 7) compared to baseline values (Chen et al., 2010). Conversely, the same study (2010) observed pre-post increases in resting SBP by ~6 mmHg in participants who were normotensive (n = 16), and no pre-post changes in DBP in either participant group was found. Similarly, another study investigating the effects of a 10-week swimming intervention in both hypertensive males and females revealed increases in both SBP (mean increase: 4.9 mmHg) and DBP (mean increase: 6.5 mmHg) (Silva et al., 2009).

With regard to vascular responses, swim training significantly improves carotid artery compliance, flow-mediated dilation and cardiovagal baroreflex sensitivity in individuals with hypertension after 12 weeks of swim training (Nualnim et al., 2012). However, no change in casual forearm vascular resistance was detected in hypertensive individuals following a 10-week swimming intervention (Tanaka et al., 1997).

In women who are obese and hypertensive, high-intensity swimming improves insulin sensitivity, decreases plasma insulin and expression of adhesion molecules linked with endothelial dysfunction (soluble intracellular cell adhesion molecule-1 and soluble vascular cell adhesion molecule-1), whereas moderate-intensity swimming does not seem to induce the same metabolic responses (Mohr et al., 2014). The same study (2014) also examined the expression of intramuscular proteins obtained via biopsies. Although phosphofructokinase protein expression, vastus lateralis muscle glycogen and lipids did not change either via high-intensity or moderate intensity swim training, citrate synthase in the deltoid muscle (but not in vastus lateralis), 3-hydroxyacyl-CoA dehydrogenase and complex i-v in the deltoid muscle, all significantly increased after both high-intensity as well as moderate intensity swim training (Mohr et al., 2014). After one year of swim training, pre-post insulin resistance improved in hypertensive individuals (Chen et al., 2010), but no significant differences have been detected in various other metabolic biomarkers, such as cytokines, glucose or insulin, haemoglobin, lipids and catecholamines in other studies on hypertensive individuals (Nualnim et al., 2012, Tanaka et al., 1997).

Similar to changes in BP, body composition responses to swimming in individuals with hypertension are inconsistent. In women who were hypertensive and obese, adiposity decreases and lean body mass increases following 15-weeks of both high-intensity (body fat % decrease: 43.1±1.1% to 41.4±1.2%; lean body mass mean increase: 1.7±0.3 kg) and moderate-intensity (body fat % decrease: 44.1±1.2 to 42.1±1.0; lean body mass increase: 1.3±0.3 kg) swim training, but no changes occurred for the same variables in controls (Mohr et al., 2014). In contrast, no changes in any body composition variable or body mass were reported as a result of swim training of various durations in three studies (Chen et al., 2010, Nualnim et al., 2012, Tanaka et al., 1997). In addition to this, swim training does not seem to have any effects on bone mineral content and/or density in premenopausal women who are obese and hypertensive (Mohr et al., 2014).

In regards to risk of bias, three studies were at high risk of selection bias due to inadequate randomisation and allocation concealment (Chen et al., 2010, Mohr et al., 2014, Silva et al., 2009), and the remaining two studies were at an unclear risk of selection bias because insufficient information was provided (Nualnim et al., 2012, Tanaka et al., 1997) (see Figure 4 and Appendix E). All of the swimming studies investigating individuals with hypertension were at a low risk of attrition bias (no or appropriate handling of missing data), and all but one was at a low risk of other sources of bias (Chen et al., 2010, due to single group design). As expected all studies were at a high risk of performance bias (lack of blinding of participants and personnel), and only one study was at a low risk of detection bias because it was the lone study to blind outcome assessors (Nualnim et al., 2012).

Although, studies have found improvements in vascular responses and lean mass, and reductions in blood pressure, insulin resistance, and body fat, the evidence is derived from non-RCTs of short duration and low sample sizes. Moreover, given that selection bias and detection bias can dramatically influence the internal validity of findings (Higgins et al., 2011), the data presented here must be interpreted with caution. There is need for higher quality RCTs of adequate duration and sample size with low risk of bias to determine the impact of swim training on blood pressure and other cardiovascular risk factors in individuals with hypertension.

Individuals with osteoarthritis

We found one eligible RCT that investigated the effects of swimming in middle age and older adults with osteoarthritis (Alkatan et al., 2016). This study (2016) randomized participants into either a 12-week swimming intervention (involving front crawl and breaststroke) or cycling programme, and revealed that physical performance (assessed via distance covered in a 6-min walk test) improved significantly in both interventions. However, vascular endothelial function (measured via brachial flow-mediated dilation) improved significantly after swimming but not post-cycling training. Whereas, significant improvements were detected in other parameters of cardiovascular function (carotid artery compliance, reduced carotid-femoral pulse wave velocity, carotid artery stiffness index, carotid artery distensibility) in both groups, others measures (blood pressure, SBP, DBP, pulse pressure, heart rate, carotid intima media thickness) did not change with either intervention (Alkatan et al., 2016).

With regards to biomarkers, only interleukin-6 and glycated haemoglobin significantly improve after 12 weeks of swimming and cycling, while no changes were observed in any other biomarker (Alkatan et al., 2016). Although, no significant changes were observed in lean body mass or body fat % in either intervention, body mass (swimming, baseline vs. post-intervention: 92.0±4.7 vs. 89.4±3.9 kg), visceral adiposity (swimming, baseline vs. post-intervention: 3.4±0.3 vs. 3.0±0.3 kg), and waist circumference (swimming, baseline vs. post-intervention: 106±3 vs. 103±3 cm) reduced significantly and similarly after both interventions. In addition, muscular strength (assessed via knee isokinetic dynamometry at both $60^{o} \cdot s^{-1}$ and $120^{o} \cdot s^{-1}$ and maximal grip strength) significantly increased similarly in both training groups (Alkatan et al., 2016).

Alkatan et al. (2016) was a generally well designed study, with a low risk of selection bias, due to appropriate randomization of participants, detection bias, because outcome assessors were blinded to participant allocation, attrition bias, as a result of utilising an intention-to-treat analysis, and other sources of bias (see Figure 4 and Appendix E). However, the study was at a high risk of performance bias due to the nature of the interventions. as it was not possible to blind participants to the intervention received, and of reporting bias, because although C-reactive protein was listed as one of its outcome variables, no outcome data regarding this variable were provided in the publications. Furthermore, although the study finds that swimming and cycling have broadly similar effects in this sample of middle-aged and older women with osteoarthritis, the lack of a control group does not preclude the possibility that these findings may have been due to regression to the mean.

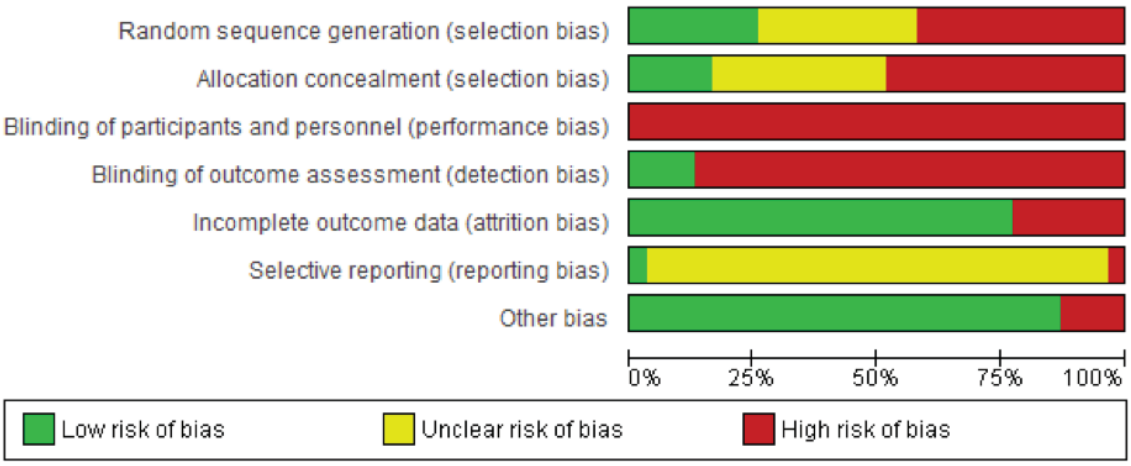
Other populations

We identified two eligible studies (both RCTs) in populations that could not be included in any of the categories above. One RCT investigated the effects of a 12-week swimming intervention on respiratory aspects of speech productions in individuals with Down syndrome (Casey and Emes, 2011). The results of this study revealed that front crawl swimming did not improve maximum phonation duration, initiation volume, and expired mean airflow. The study (2011) was at a low risk of attrition bias (minimal loss-to-follow-up) and other sources of bias. However, this study was at a high risk of both performance (lack of blinding of participants) and detection bias (lack of blinding of outcome assessors), and an unclear risk of selection bias (no method of randomization was provided) and reporting bias (insufficient information to make a judgement).

The other RCT assessed the effects of a 4-week swimming intervention (swim stroke details not reported) on the rate of ear discharge in Aboriginal children with a tympanic membrane (i.e. eardrum) perforation (Stephen et al., 2013). Children were randomized to a swimming intervention in a chlorinated swimming pool or non-swimming controls. This study revealed that a similar number of children in both groups (swimming: 24 of 41 vs. controls: 38 of 48) had ear discharge after four weeks, whereas, swimming did not affect associated bacteria in the nasopharynx and middle ear. Therefore, the authors concluded that, although swimming intervention is unlikely to substantially reduce rates of chronic suppurative otitis media (a chronic inflammation of the middle ear and mastoid cavity, usually with a perforated tympanic membrane) and related bacteria in the nasopharynx and middle ear, it did not exacerbate ear discharge and thus, should not be discouraged. This study was a well-designed study, with a low risk of selection bias (appropriate randomization and allocation concealment), detection bias (blinding of outcome assessors), attrition bias (all available data was analysed), reporting bias (all outcomes in study protocol were reported in the publication), and other sources of bias (see Figure 4 and Appendix E). Due to the nature of the intervention, the study was at a high risk of performance bias because the participants could not be blinded to the intervention received.

Figure 4.

Risk of bias of chronic swimming studies. Review authors' judgements about each risk of bias item presented as percentages across all included studies.



The acute and chronic effects of cold water swimming

Acute physiological responses to swimming in cold water

We identified five eligible studies investigating the acute physiological responses to swimming in cold water. Two of these studies were single group studies (Lombardi et al., 2011, Zenner et al., 1980), two studies were CTs (Siems and Brenke, 1992, Siems et al., 1999), and the other was single group study with crossover (Tipton et al., 1999). All studies were conducted in healthy individuals, and in three of the studies the swim group comprised of regular winter swimmers (Siems and Brenke, 1992, Siems et al., 1999, Zenner et al., 1980) (median swim group n: 15). See Table 3 for the characteristics and findings of these studies.

Two studies investigated the acute cardiovascular responses of cold water swimming (Tipton et al., 1999, Zenner et al., 1980). Significantly progressive increases in both VO_2 and HR, as well as inspiratory volume and respiratory frequency with decreasing water temperatures from 25°C to 18°C and 10°C, were demonstrated in a study that investigated competent swimmers never exposed to cold water previously (Tipton et al., 1999). In the same study, hyperventilation was observed with decreasing water temperatures. After 60 seconds of vigorous intensity swimming in cold water, SBP and DBP both remain elevated immediately post-swimming compared to baseline values (SBP: from 132±4 to 181±6 mmHg, and DBP: from 80±2 to 86±4 mmHg, levels of significance not reported) and still remain elevated up to four minutes (SBP 4-min post-swimming: 151±5 mmHg, and DBP 4min post-swimming: 84±4 mmHg, significance not reported) (Zenner et al., 1980). Although no significant heart disturbances occur after cold water swimming (Zenner et al., 1980), swimming in cold water can also cause hypothermia, and in turn, swimming-related deaths. As such, a study investigating swimming capability of 10 swimmers in cold and warm water concluded that swimming efficiency, stroke length, and core temperature decreased more (without any significant changes in cardiorespiratory responses) while swimming in cold water compared to warmer water temperatures (Tipton et al., 1999). The authors (1999) suggested that the greater drop in core temperature could be the cause swimming failure in cold water (Tipton et al., 1999).

Three studies have investigated the acute responses of swimming in selected blood parameters. In 15 individuals who swam 150m in cold water, significant increases occurred after swimming in haematocrit and haemoglobin as well as in red blood cell (4.7%) and white blood cell (40.6%) and platelet (25%) count (Lombardi et al., 2011). From the relative number of leukocytes only eosinophils significantly increase after swimming while from the absolute number of leucocyte subpopulations, significant increases were detected in the absolute number of neutrophil granulocytes, lymphocytes and monocytes (Lombardi et al., 2011). During cold-water swimming, extensive formation of oxygen free radicals occurs, however, resting levels of biomarkers of the anti-oxidative system (uric acid, glutathione, oxidized glutathione, erythrocyte superoxide dismutase, and catalase) of regular cold-water swimmers were better in cold-water swimmers compared to those observed in cold-water non-swimmers (Siems and Brenke, 1992, Siems et al., 1999). The above findings are suggestive of an adaptive response to repeated oxidative stress in winter swimmers.

The above evidence comes from relatively small sample studies with a mixture of regular winter swimmers and participants unaccustomed to winter swimming. All of the studies were at a high risk of selection bias due to no randomization of group allocation or condition order, and performance and detection bias because of a lack of blinding of participants, research personnel, and outcome assessors). One of the studies (Tipton et al., 1999) was at a risk of attrition bias because not all participants completed all conditions and excluded from analyses. Therefore, to elucidate the physiological acute effects of cold water swimming better designed randomised crossover trials in a variety of other populations are required.

Chronic physiological adaptations to swimming in cold water

Our search identified five studies investigating the chronic physiological adaptations to cold water or winter swimming (see Table 3 for characteristics of studies). Of the eligible studies, three were CTs (Gibas-Dorna et al., 2016, Hermanussen et al., 1995, Hirvonen et al., 2002) and two single group studies (Huttunen et al., 2001, Lubkowska et al., 2013). The swim intervention group consisted of regular winter swimmers in four of the studies (median swim group n: 22) (Gibas-Dorna et al., 2016, Hermanussen et al., 1995, Hirvonen et al., 2002, Huttunen et al., 2001) (for characteristics and findings of studies seeTable 3).

Hermanussen and colleagues (1995) compared healthy student's physiological responses before, and 30 and 60 minutes after a cold water swim, both on the first and last day of a 2.5 month winter swimming programme consisting of at least once weekly 2-10 minute swims. Post-winter swim training, there was an almost 50% increase in basal insulin from baseline concentrations, in addition to an inhibition of insulin secretion at 30 and 60 minutes post-cold water swim (Hermanussen et al., 1995). Moreover, slightly higher increases in cortisol concentrations from pre to 30 minutes post-cold water swim, but, uniform decreases in cortisol between 30 and 60 minutes post-cold water swim, were observed post-intervention (Hermanussen et al., 1995). Both before and after winter swim training, thyroid-stimulating hormone concentrations increased by almost 50% in all participants 30 minutes after cold water swimming, and decreased by around 20% from 30-60 minutes post-swim. No major changes were detected in prolactin, luteinizing hormone, follicle stimulating hormone or growth hormone responses before and after winter swim training, although, there was an almost two-fold increase in basal prolactin concentrations from pre- to post-winter swimming (Hermanussen et al., 1995).

Similarly, Hirvonen et al. (2002) observed no changes in plasma catecholamines, serotonin, plasma homovanillic acid and ß-endorphin values in winter swimmers before and after the winter swimming season compared to non-swimming controls. However, another previous similar study (but with no control group) found a diminished catecholamine (norepinephrine and epinephrine) response to a cold water immersion test after a winter training season, suggesting that cold adaptation induced by winter swimming may attenuate the catecholamine responses to cold water (Huttunen et al., 2001).

A study that investigated the effects of winter swimming for six months, twice a week, revealed that winter swimmers improved their insulin sensitivity compared to controls (Gibas-Dorna et al., 2016). Despite there were no significant changes in body composition parameters in the total sample of participants pre-post intervention, significant reductions were detected in fat-free mass, total body water and muscle mass in women but not in men (Gibas-Dorna et al., 2016). Similarly unchanged body composition and anthropometric characteristics with winter swimming have been observed previously (Lubkowska et al., 2013).

Lubkowska and colleagues (2013) studied the oxidant/antioxidant status of 15 healthy men who had never been exposed to cold water immersion, before and after five months of winter swimming (2-5 min swimming 2-3 times per week). The authors reported favorable changes in a number of biomarkers in the antioxidant system and a milder response to cryogenic temperatures after five months of winter-swimming. The results suggest that healthy winter swimmers have an increase capacity and efficiency of the antioxidant system and an improved defensive response to increasing oxidative stress. However, winter swimmers also experienced significant decreases in the number of red blood cells, hemoglobin and hematocrit, and increase in SBP. However, as with the favourable changes observed in this study, the clinical importance of these more unfavourable results need to be confirmed in future RCTs. Furthermore, a previous study observed no significant changes in SBP or DBP before and after the winter swimming season compared to a control group of non-swimmers (Hirvonen et al., 2002).

The findings above must be interpreted with caution due to the high risk of selection bias (none of the controlled trials did not randomise group allocation), performance and detection bias (no blinding of participants, research personnel, and outcome assessors), and attrition bias (non-completers were not included in the analyses) across studies. Furthermore, swimming protocols are often poorly reported and training is not well monitored, as such it is difficult to ascertain in the eligible studies how much swimming was performed by the participants. This makes it difficult to separate the physiological adaptations resulting from swimming to those due merely to immersion in cold water. Therefore, there is a need for well-designed RCTs with adequate sample sizes that investigate the physiological adaptations to cold water swim training in both regular cold water swimmers and participants unaccustomed to cold water swimming. Studies are also required to compare adaptations to cold water swimming versus cold-water immersion.

Summary of findings

Acute physiological effects of pool swimming

There is a paucity of recent studies investigating the acute effects of swimming on different physiological responses and systems. Up until the year 2000, there was an extensive interest to identify the cardiorespiratory and metabolic responses of swimming, however, between 2000 and 2017, there were only four eligible studies published. Based on the available evidence we can conclude the following:

Healthy children and adolescents (3 eligible studies)

- At least acutely, swimming in chlorinated pools does not appear to adversely affect Eustachian tube function or middle ear pressure in healthy children. Whether this is the case in the long-term or for children with pre-existing ear problems is currently unknown.
- Swimming may result in a reduction in free radical scavenging activity (biomarker indicative of anti-oxidative capacity), possibly due to the acute production of free radicals and other reactive species during swimming.
- Surprisingly, none of the eligible studies investigated the acute effects of swimming on important physiological systems, such as the cardiorespiratory and metabolic systems.

Healthy adults (9 eligible studies)

- During swimming, cardiorespiratory (VO_2, VE, HR, BP), metabolic (blood lactate) and hormonal (epinephrine, norepinephrine) responses correspond to increases in intensity; however, these appear to be lower compared to other modes of exercise, such as running and cycling.
- Swimming VO_2max can be ~20% lower compared to running VO_2max, and ~10% lower compared to cycling VO_2max. Similarly, swimming maximal cardiac output can be ~25% lower compared to running. However, the HRmax appears similar between swimming, running, and cycling.
- Upon cessation of swimming, HR and blood lactate may remain increased up to two hours post-swimming but SBP and DBP start to reduce one minute and five minutes post-swimming, respectively. Cardiac output responses post-swimming appear to be similar with cycling, but stroke volume appears to be lower post-swimming compared to post-cycling.

Pregnancy (3 eligible studies)

- During pregnancy, VO_2peak may decrease from the second to the third trimester. However, whether VO_2peak is different during pregnancy and up to 12 weeks postpartum is unclear. HR seems to elevate more while swimming during pregnancy versus postpartum while in contrast, metabolic responses seem to be lower during pregnancy compared to postpartum. During pregnancy and postpartum, VO_2peak may be ~10% lower for swimming compared to cycling.
- Fetal HR also rises significantly while swimming when pregnant without any pathological decelerations. Although, cases of transient fetal bradycardia can be observed during maximal swimming (~4%), these are lower compared to those seen in maximal cycling (~9%). These results collectively suggest that swimming during pregnancy is safe.

Individuals with cardiovascular disease (7 eligible studies)

- Similarly with the healthy population, cardiorespiratory responses during swimming in this population correspond to increases in intensity. However, these vary considerably according to the swimming level of the patient. Swimming appears to stress the cardiorespiratory system more compared to walking and volleyball playing, but similar to cycling for competent swimmers.
- When recommending a swimming programme for patients with cardiovascular disease, exercise physiologists should consider the following:
    1. During swimming, patients with cardiovascular disease may be less able to recognise symptoms of exercise-induced ischemia, such as angina, compared to during exercise modes like cycling.
    2. Even in those with stable chronic heart failure, performance during cycle ergometer exercise at workload of 70 or 110W (i.e., 4-6 METs) may be a good indicator of the safety of swimming in thermoneutral water.
    3. Energy expenditure, measured via VO_2peak, varies considerably according to swimming ability. For unskilled swimmers even swimming at an individual-selected comfortable speed, intensities could be close to maximal values.
    4. An inadequate chronotropic response to exercise (determined during cycle ergometry) may indicate an impaired tolerance swimming, due to a reliance on HR to maintain cardiac output in patients with reduced ejection fraction.

Limitations of evidence and recommendations for future study

- Generalisation of the findings in this review is difficult because the majority of the 22 eligible studies investigating the acute physiological responses to swimming have studied the effects of breaststroke swimming in small samples of predominantly male untrained participants. These studies tended to adopt crossover designs comparing swimming responses to mostly cycling (surprisingly, only data on 12 individuals are available comparing swimming to running).
- All but one acute study was at a high risk of selection bias due to either a lack of randomisation of group allocation or exercise condition order (the other study was at an unclear risk). None of the studies attempted

to blind outcome assessors to the purpose of the experiments and as a result were at a high risk of detection bias (all studies were at a high risk of performance bias because it is impossible to blind participants to exercise mode). Lower risk of detection bias could be achieved through the use of independent outcome assessors in each exercise condition studied.

- There is a need for better designed crossover studies of the acute physiological responses to different swim strokes (front crawl in particular) compared to other popular exercise modes (e.g., running, walking, and cycling) in children and adolescents, pregnant women, and chronic diseases populations, such as individuals with type 1 or 2 diabetes, obesity, cancer, and arthritis.

Chronic physiological adaptations to pool swimming

Compared to acute physiological responses, there is a more recent studies investigating chronic physiological adaptations to swim training (22/31 studies since 2000), with a focus on investigating individuals with co-morbidities (19 studies) rather than healthy participants. Our conclusions based on the available evidence follows.

Healthy children and adolescents (3 eligible studies)

- Swimming training improves significantly cardiorespiratory fitness as well as anti-oxidative defences compared to controls.
- It seems that healthy children that start swimming training have significantly lower gains body mass and body fat compared to controls. However, swim training does not improve posture scoliosis or scapula and shoulder asymmetry.

Healthy university students and adults (7 eligible studies)

- Significant improvements are seen in cardiorespiratory fitness, strength and lung function when the intervention is, at least, 12 weeks. Cardiorespiratory adaptations are similar to other modes of exercise, such as cycling and running, while, the swimming cardiorespiratory adaptations observed may be specific to swimming (i.e. post-intervention improvements in swimming VO_2peak, VOEmax and HRmax but no relevant increases in these variables during cycling).
- However, one relatively large 6-month RCT with a low risk of selection, attrition, and other bias, found increased SBP in sedentary older women post-swim training relative to a walking intervention (Cox et al., 2006). Although, this study also found significant increases in TC and LDL-C in the walking group at 12 months follow-up. The authors (2006) suggested that these positive impacts on lipids with swimming may counteract the increase in SBP.
- RCTs of 3-6 months duration suggest that swimming can have a modest impact on body mass, similar to running and cycling. While in the short-term at least, swimming may lower waist circumference and hip circumference in sedentary older women compared to a walking intervention.

Pregnancy (1 eligible study)

- Cardiorespiratory fitness and resting HR significantly improve from the 16th until the 28th week of gestation (i.e. 12-week intervention) in response to swim training but blood pressure responses remain unaltered while similar body mass gains are observed between swimmers and controls. Women that continue swimming after the 28th week until the 36th week of gestation appear to maintain rather than improve their cardiorespiratory fitness.

Individuals with asthma or cystic fibrosis (11 eligible studies)

- Cardiorespiratory fitness (VO_2peak and ventilatory threshold) significantly improves in children with asthma in response to swim training, however, the effects on lung function parameters are controversial, with perhaps small improvements in FEV1% predicted. Asthma severity and symptoms also may improve post-swimming interventions when the duration of the intervention is above six weeks of swimming. Lung function also can improve in adults with asthma after six months of swim training.

- Significant improvements in VO_2peak and minute ventilation, but not lung function, have been observed in children with cystic fibrosis after swimming for 12 weeks. Importantly, the clinical disease state of the patients participating in swim training may improve, compared to participants in a non-swimming control group.
- Individuals with hypertension (5 eligible studies)
- In response to swim training, cardiorespiratory fitness does not seem to increase significantly after 12 weeks but fitness in different field tests increases significantly after both moderate and high-intensity swim training. Beneficial adaptations also occur in cardiac and vascular function (apart from forearm vascular resistance) as well as biomarkers linked with vascular dysfunction.
- The majority of the studies suggest that swim training can reduce SBP in individuals with prehypertension and mild to moderate hypertension, whereas, DBP appears to remain unchanged.
- Insulin sensitivity and expression of adhesion molecules improves significantly but no significant differences have been detected in various other metabolic biomarkers, such as cytokines, haemoglobin, lipids and catecholamines.
- The majority of the available studies suggest that swimming either does not change or minimally alters body composition parameters and bone mineral content and density in adults with hypertension.
- Individuals with osteoarthritis (1 eligible study)
- Fitness (assessed via a field test) and functional parameters of the vasculature improve with swim training in a similar manner to cycling training, however, SBP and vascular structure remains unchanged after 12 weeks of both swimming and cycling. Body composition and strength also improves significantly with swim training, in a similar manner to cycling.

Other populations (2 eligible studies)

- Swimming for 12 weeks does not improve respiratory aspects of speech productions in individuals with Down Syndrome, and four weeks of swimming does not exacerbate ear discharge in children with eardrum perforation.

Limitations of evidence and recommendations for future study

- Most of the 31 eligible studies that examined the chronic physiological adaptations of swim training adopted RCT, quasi-RCT, or CT designs to compare swim training to mostly cycling or walking or running. In contrast to the acute studies, the majority of studies employed interventions comprised of front crawl or a mixture of swim strokes.
- No study included mortality or disease outcome as an endpoint, instead, the trials mostly focused on cardiorespiratory, lung function, haematological and body composition effects of swim training.
- Due to the relatively small swim training group sizes (median n = 15), it is difficult to generalise our findings to each population. In addition, most of the studies were at a high or unclear risk of selection bias (~80% of studies due to inadequate randomisation or poor reporting of method of randomisation), a high risk of performance (100% of studies) and detection bias (~80% due to inadequate blinding of participants and research personnel and outcome assessors), and a high or unclear risk of reporting bias (~95% due to insufficient information available to make a judgement). However, most trials were at low risk of attrition bias (~80% due to minimal or no loss-to-follow-up) and appeared to be free of other sources of bias (~90%).
- No study investigating the chronic physiological adaptations to swim training in children and adolescents, pregnant women, and individuals with hypertension or cystic fibrosis were RCTs, and therefore, represent low quality evidence.
- In addition, we could find no experimental data for the effects of swim training in other chronic disease groups such as individuals with type 1 or 2 diabetes and other metabolic conditions, cancer, and rheumatoid arthritis.
- Therefore, future well-designed RCTs with appropriate randomisation, allocation concealment, blinding of assessors, and handling of missing data, are required to establish the efficacy and effectiveness of different swim strokes on physiological outcomes in various populations including children and adolescents, sedentary adults, older adults, and individuals with non-communicable diseases.

The acute and chronic effects of cold water swimming

- Due to the dearth of studies (acute responses, 5 studies; chronic adaptations, 5 studies) that investigate the effects of cold water (or winter) swimming, it is difficult to form robust conclusions.
- Evidence from five eligible studies (2 pre-post single group studies, 2 CT, and 1 CT with crossover) suggests that, acute bouts of swimming in cold water can increase VO_2 and heart rate, as well as increase inspiratory volume and respiratory frequency with decreasing water temperatures, resulting in hyperventilation. Although no significant heart disturbances were reported while swimming in cold water, there is a risk of swimming failure (i.e. reduced swimming efficiency), probably because of a significant drop in core temperature.
- Evidence for the acute responses to cold water swimming comes from several relatively small sample studies comprising mostly of regular winter swimmers (3 out of 5 studies). All studies were at a high risk of selection bias (no randomization of group allocation or condition order), and performance and detection bias (no blinding of participants, research personnel, and outcome assessors). One of the studies was at a risk of attrition bias because not all participants completed all conditions.
- Five eligible studies (3 CTs and 2 single group studies) reported on the chronic adaptations to cold water swimming, with the majority consisting on regular winter swimmers (4 out of 5 studies).
- Marked increases in insulin sensitivity and basal prolactin concentrations have been observed in individuals unaccustomed to winter swimming. The chronic effects of swimming in cold water on haematological markers and blood pressure are unclear, and require further study. None or modest changes in anthropometric characteristics and body composition have been reported with winter swimming.
- Winter swimming may improve the capacity and efficiency of the antioxidant system and improve the body's defensive response to greater oxidative stress. Furthermore, cold water swimming may induce cold adaptation that may attenuate the catecholamine responses to cold water immersion.
- Chronic adaptation to cold water swimming studies were at a high risk of selection bias (both non-randomised controlled trials), performance and detection bias (lack of blinding of participants, research personnel, and outcome assessors), and attrition bias (non-completers were not included in the analyses), but appeared free of other sources of bias.
- Both acute studies with randomised crossover and chronic studies with random allocation of participants are required to establish the physiological effects of cold water swimming in populations other than those accustomed to winter swimming.

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Table 1.

Acute physiological effects of pool swimming

HEALTHY CHILDREN AND ADOLESCENTS			
First Author	Methodology	Outcome Measures (Technique)	Findings
Atsumi 2008	**Population:** 17 healthy boys and girls **Study Design:** CT **Intervention:** Measurements took place before and after different activities: a) ingestion of beverage, b) swimming for 50 min (stroke not provided) (mean age: 11.9 years), c) dancing (mean age: 5.8 years), d) comfortable/uncomfortable stimulation, e) smoking	• Free radical scavenging activity (antioxidant capacity assay method)	**Pre vs. post-swimming:** 1) Free radical scavenging activity decreased after swimming
Grace 1987	**Population:** 52 normal school children **Study Design:** CT **Intervention:** Participants were assessed pre and post-swimming on an average of four occasions. 29 children swam in high chlorine concentration and 23 in a low chlorine environment (swim stroke not provided)	• Middle ear pressure (tympanometry)	**Pre. vs. post-swimming between groups:** 1) No adverse effects on middle ear function
Morgan and Shenoi 1989	**Population:** 28 children between the ages of 4-8 (females, n=14) **Study Design:** RCT **Intervention:** One group was measured 30min post-swimming and the other group after 14 hours post-swimming (stroke not provided)	• Middle ear pressure (tympanometry)	**Pre vs. post-swimming between groups:** 1) No changes in tympanometry pre and post-swimming

HEALTHY UNIVERSITY STUDENTS AND ADULTS			
First Author	Methodology	Outcome Measures (Technique)	Findings
Boning 1988	**Population:** 10 untrained young adult males (24.4±1.5 years) **Study Design:** Single group **Intervention:** Participants were assessed: a) immersed in water for 1.5hrs, b) 1h swimming breaststroke at an intensity of 155b.min, c) for 2hrs post-exercise	• Whole blood: blood lactate and glucose (enzymatic method), osmolarity (osmometer), hemoglobin, haematocrit (microcentrifugion) • Plasma: chlorides (electrometric titration), sodium, potassium (both with ion sensitive electrodes), creatinine (color reaction with picric acid), anti-diuretic hormone (radio-immunoassay), aldosterone (RIA kit) • Urine: volume, density (aerometer), urea concentration (enzymatic method), osmolarity, sodium, potassium, chlorides and creatine (all as above) • Renal Function: parameters for renal function that were calculated from the above: GFR, creatinine clearance, osmolar clearance, free water clearance, fractional sodium excretion	**Pre vs. post-swimming:** 1) Whole blood: Significant ↑ in blood lactate, osmolarity, haematocrit, hemoglobin, sodium, creatinine and significant ↓ in glucose 2) Plasma: Significant ↑ in sodium and creatine but none of the other parameters 3) Urine: Significant ↓ in density, osmolarity, sodium and chlorides 4) Renal Function: no significant changes in any parameter
Dixon and Faulkner 1975	**Population:** 6 recreational swimmers (mean age: 25.8±3.9 years), and 6 trained swimmers (19.2±1.2 years) (only recreational swimmers included here) **Study Design:** CT with crossover **Intervention:** Tethered-swimming test (3-min swims with a 3-5-min rest period between each swim load). The work load started at 2.27 kg, and increased 1.14-kg increments until the swimmer could no longer support the weight during the 3-min swim. The treadmill-running test (5-min runs at 7 mph with a 10-min rest between each run). The test began at 0% grade, and increased until maximum voluntary physical work capacity was attained.	• Gas exchange variables (Douglas bags) • VE and respiratory rate (dry gas meter) • Cardiac output (CO_2 rebreathing method)	**Swimming vs. running:** 1) Swimming VO_2max was significantly ↓ compared to running VO_2max (25% lower; 2.66±0.52 vs. 3.58±1.03 L·min) 2) Swimming VEmax was significantly ↓ compared to running VEmax (15% lower; 93.8±18.5 vs. 110.8±23.8 L·min) 3) Swimming breathing frequency was not significantly ↓ compared to running breathing frequency (11% lower; 39±13.3 vs. 44±11.1 breaths/min) 4) Swimming CO max was significantly ↓ compared to running CO max (25% lower; 16.9±3.5 vs. 22.6±5.4 L·min) 5) Swimming change in arterial-venous oxygen difference was not significantly ↑ compared to running VO_2max (3% lower; 160±0.7 vs. 156±14.3 ml·L)

Galbo 1979	**Population:** 6 healthy males **Study Design:** Single group with crossover **Intervention:** Breaststroke swimming at 21°C, 27°C and 33°C for 1h at an intensity of 65% of VO_2peak.	• VO_2 (Douglas bags) • HR (ECG) • Blood lactate (enzymatic methods) • Catecholamines (double-isotope derivative assay) • Free-fatty acids, glucagon, insulin, growth hormone, cortisol (radioimmunoassays) • Rectal and core temperature (thermistor) and temperature of deltoid and vastus lateralis (needle thermocouples)	**Rest vs. 21°C vs. 27°C vs. 33°C** 1) Significantly ↓ VO_2 at 33°C 2) Significantly ↑ noradrenaline at 21°C and 33°C vs. 27°C 3) Significantly ↑ HR at all temperature during swimming vs. rest and was significantly ↑ at 33°C vs. 21°C and 27°C 4) Significantly ↓ oxygen pulse at 33°C vs. 21°C and 27°C 5) Significantly ↑ blood lactate at the 15th min of swimming at 21°C and 27°C vs. 33°C 6) Throughout swimming at 21°C and 33°C, blood lactate was significantly ↑ vs. rest 7) Significantly ↑ adrenaline at 21°C and 33°C vs. 27°C 8) 15 min post swimming at 21°C, catecholamines remained significantly elevated; at 27°C and 33°C they declined but were still higher vs. rest 9) More rapid ↑ cortisol at 33°C vs. 27°C within 30min of swimming 10) Significantly ↑ growth hormone at 27°C and 33°C but no changes in both growth hormone and cortisol at 21°C either during or post-swimming 11) Significantly ↓ glucagon at 27°C and 33°C (after both 15 and 30min of swimming) below resting values; no changes at 21°C 12) Significantly ↓ glucose only after swimming at 27°C 13) Significantly ↓ insulin during swimming vs. rest 14) Significantly ↑ insulin at all temperature but at after swimming 21°C only, remained significantly ↓ vs. rest 15) Significantly ↓ free-fatty acids and glycerol at the start of swimming at all temperatures but then significantly ↑ during swimming and remained significantly ↑ vs. rest 16) Rectal and muscle temperatures significantly ↑ at 27°C and 33°C; at 21°C rectal and deltoid only temperatures ↓

Holmer 1972	**Population:** 4 participants who were not swim trained (mean age: 28 years, range: 19-47 years, 2 male and 2 female). (Data from 2 elite and 3 swim trained and 12 elite school girls were not included here) **Study Design:** CT with crossover **Intervention:** Maximal work rates were compared during running (treadmill with 3° incline), cycling (ergometer at 50rpm), and swimming (in swimming flume, 2 participant used breaststroke, and 2 used backstroke), respectively.	• VO_2 (via Douglas bags) • HR (ECG), • Blood lactate concentrations (fingertip blood sample analysed via modified Barker-Summerson method)	**Swimming vs. running vs. cycling:** 1) Mean swimming VO_2max was 19.4% ↓ than running VO_2max and 10.3% lower than cycling VO_2max (3.03 vs. 3.76 vs. 3.03 L·min) 2) Mean VEmax was ↓ during swimming (108.4 L·min) compared to running (129.2 L·min) and cycling (114.1 L·min) 3) Mean HRmax was ↓ during swimming (18 bpm) compared to running (190 bpm) and cycling (181 bpm) 4) Maximal blood lactate response during swimming was ↑ in two participants, ↓ in one participant, and the same in one participant compared to running. 5) Maximal blood lactate response during swimming was ↑ in three participants and was ↓ in one participant, compared to cycling.
Holmer and Bergh 1974	**Population:** 2 untrained (aged 27 years) and 5 well trained swimmers (only untrained swimmers data included here) **Study Design:** CT with crossover **Intervention:** Maximal swimming test started at 0.5-0.8 m/s; water velocity was increased by 0.1 m/s every other min until the swimmer was completely exhausted (within 5-8 min). Running was performed on a treadmill, inclined 3° (5.25 %). The maximal running test was performed at a constant velocity (12-13 km/h) while the treadmill was further inclined 1.5° (2.6 %) after both 3 min and 6 min.	• VO_2max (via Douglas bags) • HR (ECG), • Blood lactate concentrations (fingertip blood sample analysed via modified Barker-Summerson method) • Oesophageal and muscle temperature (at the level of the heart via a thermocouple connected to a Honeywell recorder (Electronik 19)	**Note:** Only the untrained VO2max data was provided separate from trained, thus, only these data are included here). **Swimming vs. running:** 1) Swimming VO_2max was on average 20% ↓ than the running VO_2max
Lakin 2013	**Population:** 21 untrained (n=11) and triathletes (n = 10) (females, n=10) **Study Design:** CT with crossover **Intervention:** 30 min swimming (stroke not provided) or cycling at 60-70% of HRmax; assessments occurred at baseline, post exercise and in recovery post-exercise every 20 min intervals till the 95 min of recovery	• BP (photoplethysmography) • CO, SV and TPR (pulse contour analysis software) • Cardiac autonomic function (HRV) • Respiratory frequency (respiration module) • Skin and core temperature (hard-wired thermistors and tympanic ear temperature)	**Swimming vs. cycling responses in untrained participants:** 1) Similar HR responses in the two exercise modes 2) Significantly ↓ body mass only after swimming 3) Significantly ↑ 1min post-exercise SBP in cycling vs. swimming and significantly ↑ DBP at 1, 3 and 5min post-cycling exercise vs. swimming 4) Significantly ↓ SBP during both cycling (up to 50min) and swimming (up to 75min) recovery 5) Significantly ↓ DBP only during swimming recovery (up to 75min) 6) No significant differences in CO and TPR during recovery in any mode 7) Significant ↓ SV during all time points of recovery vs. cycling

			8) No significant differences detected between swimming vs. cycling in HRV 9) Significant ↓ in core temperature at 2, 4 and 6min immediately after swimming and throughout recovery vs. cycling
Ueda 1995	**Population:** 17 healthy physical education University students (females, n=10) **Study Design:** Single Group **Intervention:** Participants were assessed: a) at rest, b) after immersion and c) during breaststroke tethered swimming in a constant position at different speed/drags until exhaustion	• VO_2 (Douglas bags) • HR (ECG) • Blood lactate	**Responses during different speed/drags:** 1) Progressive ↑ VO_2, HR and blood lactate corresponding to the progressive increases in intensity for both male and females (significance not reported)
Viti 1989	**Population:** 8 young healthy untrained (females n=3) (mean age: 22.3±2.9 years) **Study Design:** Single group **Intervention:** Participants measured after: a) 20 min in a supine posture, b) 20 min of horizontal immersion and c) 20 min of backstroke swimming	• HR • Haematocrit (centrifugion) • Blood lactate and glucose (enzymatic methods) • Plasma proteins (biuret method) • Renin, aldosterone, arginine vasopressin, atrial natriuretic peptide (all with radioimmunoassays)	**Pre vs. post-swimming:** 1) Significant ↑ in HR, haematocrit and blood lactate post-swimming 2) Significant ↑ in atrial natriuretic peptide, plasma renin, aldosterone post-swimming 3) No significant changes in arginine vasopressin post-swimming
Weiss 1988	**Population:** 12 male University students (aged 22-25 years) adapted to swimming but not trained, trained at intensities around their anaerobic threshold for 2-3 weeks prior to tests **Study Design:** Single group with crossover **Intervention:** Participants swam whole breaststroke for 10min, and then after a pause of 4-5min they swam 150m at maximal speed. One and two weeks later the tests were repeated using only arms or only legs for 10 min at submaximal and 100m at maximal intensity. Recovery was assessed as 20 min post-exercise	• HR (counted manually) • BP (sphygmomanometer) • Blood lactate, and glucose (enzymatic methods), • Catecholamine (HPLCA) • Plasma renin activity, aldosterone, cortisol (all with RIA kits) • Electrolytes in plasma and urine (flame photometry) • Hematocrit (microcentrifuge technique) and total plasma protein (biuret method)	**Submaximal vs. maximal swimming:** 1) Progressive (significance not reported) ↑ in SBP (but not DBP) from rest to submaximal and maximal efforts 2) Significant progressive ↑ HR from rest to submaximal and maximal efforts and more pronounced increases in whole breast-stroke; HR did not reach pre-testing levels at 20 min recovery 3) 10 min swimming at submaximal intensity increased blood lactate near the anaerobic threshold only after leg swimming (significance not reported); at maximal intensity, higher blood lactate when swimming whole breast-stroke (significance not reported) 4) Significant progressive ↑ in norepinephrine from rest to submaximal and maximal efforts and more pronounced increases in whole breast-stroke; norepinephrine did not reach pre-testing levels at 20 min recovery 5) Progressive (significance not reported) ↑ in epinephrine at submaximal and maximal efforts; significantly ↓ epinephrine at submaximal arm swimming vs. whole stroke; returned to baseline levels post-swimming

			6) No changes in aldosterone an renin 7) Progressive (significance not reported) ↑ in ACTH; ↑ ACTH in submaximal and maximal whole body swimming 8) Progressive (significance not reported) ↑ in hematocrit and was higher after whole-body swimming 9) Cortisol significantly ↑ only with whole body maximal swimming 10) Significant ↑ in total protein under all conditions 11) Significant ↑ in sodium under all conditions except leg work 12) Significant ↓ in potassium swimming whole stroke

PREGNANCY

First Author	Methodology	Outcome Measures (Technique)	Findings
McMurray 1991 Also: Watson 1991	**Population:** 13 untrained healthy pregnant women **Study Design:** Single group with crossover **Intervention:** Women were assessed at 24-26 weeks and 33-36 weeks of their pregnancy as well as at 9-11 weeks postpartum for their maximal oxygen uptake during cycling and breaststroke tethered-swimming	• VO_2, VE, RER (gas analysis) • HR (electrocardiography) and fetal HR • BP and umbilical and uterine artery systolic diastolic ratios • Hemoglobin, haematocrit (centrifugion) • Total plasma protein (hand-held refractometer)	**Swimming vs. cycling at 25 and 35 weeks of gestation and postpartum:** 1) Significantly ↑ VO_2peak and VE with cycling vs. swimming at 25 and 35 weeks but similar VO_2peak at postpartum 2) Significantly ↓ VO_2peak with progression of pregnancy only in swimming 3) Significantly ↑ RER with cycling vs. swimming at 25 and 35 weeks gestation weeks and postpartum 4) Similar maternal HRmax and blood lactate responses between swimming and cycling at 25 and 35 weeks gestation weeks and postpartum 5) No significant differences in exercise-related fetal HR responses with cycling and swimming 6) Significant ↑ in haematocrit, haemoglobin and plasma protein with both swimming and cycling; all these were significantly ↓ during pregnancy vs. postpartum 7) After correction for fetal HR, no significant differences were detected in umbilical artery systolic/diastolic ratio after exercises, and no differences between cycling vs. swimming 8) Uterine artery systolic/diastolic ratio significantly ↓ post-exercise and was significantly ↓ post swimming vs. cycling

Spinnewijn 1996	**Population:** 11 sedentary or recreationally active pregnant women **Study Design:** Single group with crossover **Intervention:** Participants underwent different breaststroke tethered-swimming and cycling tests: a) for familiarization, b) at 30-34 weeks of the pregnancy and c) 8-12 weeks postpartum	• VO_2, VCO_2, VE, RER (all with gas analysis) • HR (Polar) • Blood lactate (oxidation method)	**Swimming vs. cycling during pregnancy (30-34 weeks gestation) vs. postpartum:** 1) VO_2peak during either swimming or cycling did not differ significantly between pregnancy vs. post-partum 2) Significantly ↓ VO_2peak and VE in swimming vs. cycling both during pregnancy and postpartum 3) VO_2 plateau was reached in 73% of the maximal tests 4) VCO_2 was significantly ↓ during pregnancy vs. postpartum for swimming (but not cycling) 5) No significant differences in HR between swimming and cycling either during pregnancy or postpartum 6) Significantly ↓ blood lactate during pregnancy vs. postpartum with swimming and cycling
Sasaki 1993	**Population:** 17 women with normal pregnancy at 35-38 weeks of gestation **Study Design:** Single Group **Intervention:** Fetal HR was measure before, during and after swimming (average time swimming for all participants: 33-41 min but swim stroke not provided)	• Fetal HR (ultrasound modified for underwater measurements)	**Pre vs. during vs. post-swimming:** 1) Fetal HR significantly increased during swimming vs. rest 2) No pathological deceleration in fetal HR was seen

INDIVIDUALS WITH CARDIOVASCULAR DISEASE

First Author	Methodology	Outcome Measures (Technique)	Findings
Bucking and Krey 1986	**Population:** 4 currently symptom-free males who have sustained a transmural infract 6-10 weeks previously. **Study Design:** Single group with cross-over **Intervention:** Participants assessed: a) after been immersed, b) 5 min swimming at 25m/min (stroke not provided), c) 5 min cycling at 100 W	• Pulmonary arterial and capillary pressures • Oxygen saturation	**Swimming vs. cycling:** 1) Significantly ↑ pulmonary capillary pressure and oxygen saturation in swimming vs. cycling 2) No cardiac arrhythmias reported in water

Fletcher 1979	**Population:** 22 untrained individuals post uncomplicated MI, at least 12-weeks post MI **Study Design:** Single group with crossover **Intervention:** On separate days participants: a) walked/jogged (5-7 mph for 5min, b) played volleyball (20min game) and c) swam (100 feet freestyle (mean time of 85 seconds in a pool heated to 30±10°C)	• VO_2 (Douglas bags for swimming and gas analysis for other activities, but the two methods were tested for variation and there were no differences) • Peak oxygen pulse • HR • Rate pressure product	**Swimming vs. walk/jog vs. volleyball in untrained:** 1) Higher VO_2 in swimming vs. both walk/jog and volleyball (significance not reported) 2) Higher peak oxygen pulse, HR and rate pressure product in swimming vs. both walk/jog and volleyball (significance not reported)
Heigenhausen 1977	**Population:** 6 males with previous MI (16 to 27 months) and 6 healthy inactive controls **Study Design:** CT with crossover **Intervention:** All participants performed both a cycling and a tethered swimming incremental test to exhaustion. Increments in intensity occurred every 3 minutes with 5 min rests after every increment (4 participants swam front crawl, 1 breaststroke and 1 sidestroke)	• Inspired gas (dry gas meter) and expired gas (Douglas bags) • CO (estimated via CO2 rebreathing) • HR (ECG) • Stroke volume (equation based on the data above) • Oxygen partial pressure (paramagnetic analyser)	**Swimming vs. cycling:** 1) Linear ↑ in VO_2, HR and CO in all participants with intensity during both swimming and cycling 2) No significant differences between cycling vs. swimming in any of the variables for controls 3) Significantly ↓ CO and significantly ↑ HR at any given VO_2 for patients (but not controls) during swimming vs. cycling 4) Significantly ↓ CO, SV, VO_2 and significantly ↑ ventilation equivalents in patients during swimming vs. cycling
Lehmann and Samek 1990	**Population:** 13 CAD patients with mild left ventricular cardiac damage (Group 1), 12 CAD patients with marked left-heart damage (Group 2) and 8 healthy controls **Study Design:** CT with crossover **Intervention:** Group 1 and controls swam breaststroke for 3 times x 3 min. Groups 2 and controls swam breaststroke for 3 times x 2 min	• Echocardiography (ECG) • BP (sphygmomanometer) • Blood lactate and glucose (enzymatic method) • Adrenaline and noradrenaline (radioenzymatic method)	**Group 1 vs. group 2 vs. controls:** 1) Group 1: No arrhythmias occurred during swimming and Group 2: arrhythmias occurred in 3 patients 2) Significantly ↑ BP and blood lactate in controls vs. both Groups 1 and 2 at 3min and 6min (but not at 9min of post-swimming) 3) No significant differences between groups in HR during or after swimming 4) Significantly ↑ blood lactate and noradrenaline in Group 1 and controls vs. Group 2 5) No significant differences between groups in glucose and adrenaline during or after swimming 6) Significantly ↓ noradrenaline in Group 2 vs. both Group 1 and controls only at 6th min of swimming
Madger 1981	**Population:** 8 males with a previous MI, and ST segment depression or angina at stress test. **Study Design:** Single group with crossover **Swim intervention:** All participants performed 2 cycling and 2 breaststroke swimming tests (swimming comfortably) at 25.5°C and 18°C.	• VO_2 (continuous gas analyses in cycling and Douglas bags in swimming), • VE (argon dilution method) • ECG (12 lead in cycling and telemetrically transmitted from one chest lead during swimming), HR (cardiotachometer)	**Swimming 25.5°C vs. 18°C:** 1) Similar VO_2 and HR responses while swimming in 25.5°C and 18°C 2) 81% and 83% of VO_2peak was required while swimming in 25.5°C and 18°C, respectively

			3) 5 participants did not report differences in RPE while swimming in 25.5°C and 18°C and three participants found it easier to swim in 18°C 4) 6 individuals had ST segment depression in both 25.5°C and 18°C, 2 had angina in 25.5°C, 1 in 18°C **Swimming vs. sitting and supine cycling:** 1) No significant differences in VO_2peak between swimming vs. sitting cycling 2) No significant differences in HRmax, VE and oxygen pulse between swimming vs. cycling tests 3) Significantly ↑ VO_2peak while swimming at 25.5°C vs. supine cycling 4) 4 participants had angina and ST segment depression during sitting cycling 5) 5 participants had angina and 6 ST segment depression in supine cycling; the same 6 participants had ST segment depression during both swims. 6) Only 2 participants had angina in warm water and 1 in cold water 7) ST segment depression occurred at the same HR during swimming and cycling
Meyer and Bucking 2004	**Population:** 98 individuals: 16 post moderate MI, 4 post severe MI, 18 with moderate heart failure, 5 with severe heart failure, 55 healthy individuals **Study Design:** CT with crossover **Intervention:** Participants assessed: a) at rest, b) after been immersed in water 32°C, c) 5min slow breaststroke swimming at a speed of 20–25 $m \cdot min^{-1}$, d) during supine cycling	• HR (ECG) • Mean pulmonary artery pressure • Mean pulmonary capillary pressure (both with oxymeter)	**Swimming vs. cycling:** 1) Similar HR responses during swimming and cycling ↑ mean pulmonary artery pressure during swimming vs. cycling 2) During swimming, there was a smaller decrease in mixed venous oxygen saturation vs. cycling ↑ in mean pulmonary capillary pressure but this increase was smaller compared to cycling 3) For both swimming and cycling, the mean pulmonary capillary pressure reached pathologic values, which were slightly higher for swimming
Schmid 2007	**Population:** 30 males: 10 with stable CHF, 10 with CAD and 10 healthy controls **Study Design:** CT with crossover **Intervention:** Participants assessed at: a) rest before getting into the pool, b) after immersion and c) after a "jumping-jack" exercise for 30sec and a 60sec swim (stroke not provided) along the edges of the pool	• VO_2 (gas analysis) • HR and BP • SV, cardiac index and systemic vascular resistance (infrared photoacoustic gas analyzer) • Oxygen saturation of haemoglobin	**Controls vs. CAD vs. CHF during swimming:** 1) Significant ↑ only between healthy vs. CHF but none of the other groups; VO_2 ↑ to 9.7, 12.4 and 13.9 ml/kg/min in CHF, CAD and controls, respectively ↑ HR in all groups vs. rest (significance not reported)

			2) Significantly ↑ SBP and DBP in CAD vs. healthy, but none of the other groups; SBP up to 122, 143 and 130 mmHg in healthy, CAD and CHF, respectively 3) Significantly ↑ SV healthy vs. both CHF and CAD, and significantly ↓ SV in CHF vs. CAD; SV ↑ by 47%, 30% and 35% in healthy, CAD and CHF, respectively 4) Significantly ↑ cardiac index in healthy vs. both CAD and CHF; significantly ↑ cardiac index in CAD vs. CHF 5) Significantly ↓ vascular resistance in healthy vs. both CAD and CHF; vascular resistance ↓ further by 33% in CAD and CHF patients, and 43% in controls

Abbreviations. CT: controlled trial, VO_2: oxygen uptake, VE: minute ventilation, RER: respiratory exchange ratio, VCO_2: carbon dioxide production, HR: heart rate, HRmax: maximum heart rate, BP: blood pressure, SBP: systolic blood pressure, DBP: diastolic blood pressure, GFR: glomerular filtration rate, MI: myocardial infarction, CO: cardiac output, SV: stroke volume, TPR: total peripheral resistance, HRV: heart rate variability, RPE: rate of perceived exertion, ECG: electrocardiography, CHF: chronic heart failure, CAD: coronary heart disease.

Table 2.
Chronic physiological adaptations to pool swimming

HEALTHY CHILDREN AND ADOLESCENTS			
First Author	Methodology	Outcome Measures (Technique)	Findings
Bielec 2013	**Population:** 230 6th grade junior high school students (females, n=106) **Study Design:** CT **Duration:** 2 year **Swim Intervention:** 116 adolescents attended swimming (front crawl, backstroke, and breaststroke) classes once a week, for 45min within obligatory physical education **Comparison group:** 114 controls	• Body mass, BMI • Posture, shoulder and scapula asymmetry (clinical examination)	**Swimming vs. control:** 1) Body mass was significantly lower after 1 year in swimming vs. controls, but there was no significant difference between groups at 2 years 2) No differences in BMI and posture in swimming vs. controls 3) No improvement in scoliosis or scapula and shoulder asymmetry in swimming vs. controls **Male vs. female in swimming group** 1) Gains in body mass lower in swimming males vs. females

Gonenc 2000	**Population:** 12 untrained children **Study Design:** Single group **Duration:** 4 weeks **Swim Intervention:** basic swimming training 2 per week, and swimming technique education (stroke not provided)	• Superoxide dismutase, glutathione peroxidase, plasma thiobarbituric acid reactive substances (Randox test combination)	**Pre vs. post-swim training:** 1) Significant pre-post ↑ Superoxide dismutase 2) Significant pre-post ↓ malondialdehyde (responsible for changes in plasma thiobarbituric acid reactive substances) 3) No significant pre-post change in glutathione peroxidase
Obert 1996	**Population:** 14 pre-pubertal girls **Study Design:** CT **Duration:** 1 year **Swim Intervention:** 5 girls participated from a local youth swimming club and were followed for 1 year of swimming (breaststroke, training progressed from 10h/week training during the first 3 months, to 12h/week) **Comparison group:** 9 from a primary school acted as controls. They participated in other sports 1 to 4 h/week	• VO_2peak, RER, VE (swim bench test), HR (ECG continuously monitored during fitness test) • Body mass, body fat % and lean body mass (via Skinfold thickness) • Maturation (Tanner test)	Swimming vs. non-swimming active control: 1) Significant pre-post ↑ in VO_2 peak (L·min) in both groups 2) Significant pre-post ↑ in VO_2 peak (ml·min^{-1}·kg-1·mb), HRmax, VEmax (L·min), and maximal O_2 pulse in swim group only 3) No change pre-post in RER in both groups 4) Significant pre-post ↑ body mass and ↑ in lean body mass in both groups 5) No change pre-post in body fat % in swim group but significant ↑ in control group

HEALTHY UNIVERSITY STUDENTS AND ADULTS

First Author	Methodology	Outcome Measures (Technique)	Findings
Celik 2013 Also: Ozdemir 2010	**Population:** 48 healthy with 44 completed the study, sedentary, male university students **Study Design:** RCT **Duration:** 12 weeks **Swim Intervention:** n=11, front crawl swimming (40min per day, 3 times/week, 30min swimming with 10min warm-up / cool-down, at 60-70% of HRres) **Comparison groups:** running (n=11), cycling (n=11) , control (n=11) groups	• VO_2peak (gas analysis) • Serum cartilage oligomeric matrix protein (ELISA) • BMI, body composition (DEXA) • Muscular strength (isokinetic dynamometry)	**Pre-post swimming vs. running vs. cycling vs. control:** 1) Significant ↑ in VO_2peak in all exercise groups compared to control 2) Significant pre-post change in serum cartilage oligomeric matrix protein (COMP) in the swimming group vs. control, but post-intervention 30 min of walking exercise significantly ↑ serum-COMP levels of the swimming group 3) Significant ↓ in BMI in all exercise groups compared to control 4) No significant change in body fat % between groups 5) Relative isokinetic strength of the dominant leg during extension significantly ↑ only in the swimming group compared to control

Cox 2006 Also: Cox 2008 Cox 2010	**Population:** 116 women aged 50-70 **Study Design:** RCT **Duration:** 6 month **Swim Intervention:** n=56, 60-70% of predicted HRmax, 45min, including 15min warm-up and stretching; initially interval then more continuous swimming (front, backstroke, breaststroke, sidestroke) **Comparison group:** walking (n=60) Participants further randomized to behavioral intervention or usual care. The program continued unsupervised for another 6 months	• Predicted VO_2max and performance (12 min swim and 1.6km walking tests) • BP (automatic device) and HR • Lipids (commercial kits), glucose (automated analyzer), insulin (immunoassay) • Sodium and calcium excretion (urine sample) • Body mass, BMI, upper arm girth (tape), triceps skinfold (caliper), body fat distribution (circumference in various body parts) • Food intake (diary) and Physical activity (questionnaire)	**Swimming vs. walking:** 1) Significant pre-post 6 m ↑ in predicted VO_2max and supine and standing HR were observed in both groups. No between group differences were observed at 6 m. Significant pre-post ↓ in walk time in walk test in both groups (-3.8% vs. -6.5%), but significant pre-post ↑ distance swam in swim test in swimming group but not the walking group (29.3% vs. -1.0%) 2) Significant pre-post 6 m and between groups ↑ in supine and standing SBP in the swimming group vs. the walking group (adjusted for initial BP, age, hypertension treatment status and change in weight). (Increase in supine SBP of 4.4 mmHg, 95% CI 1.2 to 7.5, in swim group relative to walking group). No significant within groups or between groups changes in DBP were observed at 6 m 3) No pre-post or between group difference in urinary sodium and calcium excretion, total cholesterol, HDL-C, LDL-C, and triglycerides at 6 m; however, at 12 m follow-up, total cholesterol and LDL-C increased significantly in the walking versus swimming group. 4) No significant within or between group differences were observed for fasting glucose, glucose area under curve (AUC), fasting insulin, and HOMA-IR at 6 m and 12 m, except for a significant increase in insulin AUC at 6 m but not 12 m in walking versus swimming. 5) Significant pre-post ↓ in body mass and BMI in swimming group but not in walking group; whereas, no between group differences were observed at 6 m, but at 12 m follow-up, the walking group had significantly higher body mass and BMI compared to swimming group 6) Waist circumference was significant lower in the swim group vs. walk group at 6 m but not at 12 m follow-up, whereas, hip circumference was significantly lower in the swim group vs. walk group at both 6 m and 12 m 7) Significant pre-post ↓ in arm muscle girth in swimming group but not in walking group, but no significant pre-post changes in triceps skinfold in with groups and no between groups differences were observed at 6 m and 12 m for arm muscle girth. 8) Calf girth was significantly lower in the swim group vs. walk group at 6 m and 12 m follow-up, but no other between group differences observed in any other anthropometric measure (forearm, chest, gluteal thigh, and mid-thigh girth)

Fernandez-Luna 2013	**Population:** 39 heathy adults (female, n=5) **Study Design:** CT **Duration:** 3 months **Swim Interventions:** a) chlorinated indoor pool (n=13); b) ozone indoor pool (n=13). Swimming training consisted of 2–3 non- consecutive sessions/week, 50min ("swimming styles technique") **Comparison group:** controls (n=13)	• Lung function (spirometry), • Lung epithelial damage (serum proteins CC16 and SP-D) • Health survey about frequency of health complaints during training (questionnaire)	**Swimming in chlorinated pool vs. swimming in ozone pool vs. control:** 1) Significant pre-post ↑ in FVC and FEV1 in Ozone pool group, but only a significant pre-post ↑ in only FEV1 in chlorinated pool group. 2) Significant pre-post ↓ in FEF 25-75 in chlorinated pool only 3) No changes in pre-post forced expiratory volumes in the control group 4) Significant pre-post ↑ in Serum CC16 in chlorinated pool only but no significant pre-post change in SPP-D occurred in any of the groups 5) Perceived health problems were similar between swimming groups, but elf-reported eye irritation was significantly ↑ in chlorinated pool compared to ozone pool.
Lavin 2015	**Population:** 20 healthy adults (female, n=10), 18 completed the study **Study Design:** RCT **Duration:** 4 weeks (12 sessions, 3 sessions per week) **Swim Interventions:** a) n=8, front crawl swimming with controlled frequency breathing; and b) n=10, front crawl swimming with stroke-matched breathing. For both interventions, sessions were 3 x week, swimming 16 x 25-yard lengths in the prescribed breathing style, with 45-s to complete each length.	• VO_2peak and running economy (gas analysis) • Pulmonary function (spirometry), diffusing capacity (Roughton–Forster technique), maximum inspiratory and expiratory pressures of the mouth, and maximum voluntary ventilation • Swimming performance (150-yard front crawl time trial) • Body mass, BMI	**Controlled frequency breathing swimming vs. stroke-matched breathing swimming:** 1) No pre-post change in VO_2max and submaximal exercise variables (HR, RER, or RPE) in either group. 2) Running economy improved overall following training (CFB group = -15 $ml \cdot kg^{-1} \cdot km^{-1}$ vs. stroke-matched group = -8 $ml \cdot kg^{-1} \cdot km^{-1}$) 3) A pre-post significant ↑ in FVC and ↓ in FEV1/FVC were apparent in the stroke-matched group, but not in the CFB group. 4) Maximum inspiratory pressure and voluntary ventilation were unaffected by training, however, when data were pooled from both groups, an overall beneficial ↑ in maximal expiratory pressure was evident after training. 5) No other changes in pulmonary function were observed, apart from a significant (but below the smallest meaningful change) ↓ in alveolar volume 6) No significant pre-post or between group difference in body mass and BMI in either group. 7) Both groups demonstrated an improvement in completion of the 150-yard time trial.
Magel 1975	**Population:** 30 male, college age, recreational swimmers **Study Design:** CT **Duration:** 10 weeks	• VO_2max, VEmax, RER (gas analysis) • HR and work time	**Pre vs. post-swimming intervention:** 1) Significantly ↑ VO_2max (380 ml/min, 11.2%), VEmax (14.9 L/min), and max swim time (4.0 min) evaluated by tethered swimming VO_2max test

	Swim Intervention: n=15, interval swim (front crawl) training procedures 1 h/day, 3 days/week Comparison groups: 15 control participants who did not participate in any form of training		2) Significantly ↓ HRmax (3.5 bpm) during swimming VO_2max test 3) No significant improvement in VO_2max (1.5%) when the same subjects were evaluated by the treadmill running test. 4) No significant changes in VO_2max and associated measures during running and swimming tests for control participants.
Soultanakis 2012	**Population:** 16 collegiate untrained swimmers (females, n=7), 13 completed the study **Study Design:** RCT **Duration:** 4 weeks **Swim Interventions:** a) n=6, high-intensity (sprint) swimming; or b) n=7, high-volume (sprint with additional endurance training) swimming. Both interventions 3 times/week and front crawl swimming	• Lactate threshold and performance trials, lactate threshold velocities, lactate concentrations at lactate threshold, peak lactate • Swim sprint performance over 50-m	**Sprint swimming vs. sprint + endurance swimming:** 1) Significant pre-post ↑ in sprint performance of 50-m maximum time and peak velocity 2) Significant pre-post ↑ swimming velocity corresponding to lactate threshold only in the sprint + endurance group 3) Pre-post peak lactate and lactate concentrations at LT did not significantly change in either group.

PREGNANCY

First Author	Methodology	Outcome Measures (Technique)	Findings
Lynch 2007 Also: Lynch 2003	**Population:** 39 pregnant women **Study Design:** CT **Duration:** 12 weeks **Swim Intervention:** n=27, 3 times/week, 40min/session, <70% of HRmax) from 16 to 28 weeks of gestation. 9 women carried on swimming until 32 weeks of gestation and 7 up till the 36 week of gestation (swimming: front crawl/backstroke/breaststroke/skill drills) **Comparison group:** non-swimming pregnant controls (n=12)	• Physical work capacity and RPE (submaximal cycling test) at 16, 20, 24 and 28 weeks of gestation (and 32 and 36 of those women who continued), • BP (sphygmomanometer), umbilical artery systolic/ diastolic ratio • Maternal and fetal HR • Body mass • Rectal temperature	**Swimming vs. non-swimming control:** 1) Significant ↑ physical work capacity of the swimming group but not controls. Significant ↑ physical work capacity at 20 weeks and at 24 weeks of gestation (13.8% improvement over 8 weeks) but no further improvement from 24-28 weeks of gestation 2) No significant changes in relative physical work capacity were identified in either group over the 12-week training period, despite body mass increasing by approx. 6 kg in each group. 3) No significant changes in pre-exercise or exercise HR were observed over the study period. 4) Significant ↓ RPE after 4 weeks of training (20 weeks of gestation) of swimming but no changes thereafter 5) No differences in rectal temperature pre-post swim intervention 6) No difference in body mass gain to 28 weeks gestation between groups 7) No adverse responses to exercise were identified in any individuals

			Pre vs. post-swimming: 1) Significant ↓ in HR 5 min post-swimming at all gestational weeks 2) Mean resting HR significantly ↓ advancing gestation age, but no change was observed in exercising and post-exercise rates 3) Significant ↓ in resting and post-swimming fetal HR with advancing gestation, but no effect on the pre- and post-exercise fetal HR differences with advancing gestational age 4) Significant ↑ in fetal HR during and 5 min post-swimming 5) Resting SBP and DBP remained unchanged over gestation 6) No significant accelerations in fetal HR were detected or signs of hypoxia and no significant changes in umbilical artery systolic/diastolic ratio, pre-post swim intervention

INDIVIDUALS WITH ASTHMA AND CYSTIC FIBROSIS

First Author	Methodology	Outcome Measures (Technique)	Findings
Arandelovic 2007	**Population:** 65 adults with persistent asthma (female, n=49) **Study Design:** RCT **Duration:** 6 months **Swim Intervention:** n=45, 1h swim (stroke not reported), 2 times/week (non-chlorinated pool), asthma education **Comparison group:** controls treated with inhaled corticosteroids and short acting -2 agonist salbutamol (n=20)	• Lung function (spirometry), • Bronchoprovocative test (dosimeter device) • Skin tests (skin prick test)	**Swimming vs. controls post-intervention:** 1) Significant ↑ FEV1, FVC, PEF in the swimming group vs. controls 2) Significant better responses in the bronchoprovocative test in both groups 3) Significant ↓ in the bronchoprovocative test for atopic and atopic individuals in both groups 4) At the end of the study, hyper-responsiveness was significantly ↓ in the swim group compared to the control group **Pre-post swimming in swim group only:** 1) Significant pre-post ↑ in FEV1, FVC, and PEF
Bemanian 2009	**Population:** 96 girls who took part in swimming class **Study Design:** CT **Duration:** 2 months **Swim Intervention:** 3 days per week. Girls were divided into a) asthmatic patients, b) allergic rhinitis, c) atopic dermatitis, d) healthy (swim stroke not provided)	• Spirometry at beginning, one hour after swimming and two months later	**Pre vs. post-swim training:** 1) Overall, significant ↑ in PEF rate more than 20% of personal best was seen in 21 girls after one hour swimming as well as at 2 months 2) Significant ↑ in PEF rate at 2m in healthy individuals, asthmatic patients and girls who were obese, but was not significant in patients with allergic rhinitis or eczema

Fitch 1976	**Population:** 56 schoolchildren **Study Design:** CT **Duration:** 5 months **Swim Intervention:** n=46 asthmatic schoolchildren started from 3 days/week, progressed to 5 days/week, with subsequent increases in intensity. Post intervention the children were divided based on the total distance they swam: a) <50km (n=14), b) 50-100km (n=16) and c) >100km (n-16) (swim stroke not reported) **Comparison group:** n=10 children without asthma history that started a similar swimming program	• Fitness (submaximal 9 min treadmill test with 3 min stages to achieve HR of 180-190 bpm at the end of the test) • Lung function (spirometry) at baseline and 5min intervals • Anthropometric assessments including chest circumference and diameter, fat mass (caliper) • Posture	**Asthma swimming group vs. non-asthma swimming group:** 1) Significant ↑ fitness in all groups but more pronounced increases in both groups that swam 50-100km and >100km vs. <50km 2) No significant changes in FEV1, FVC and exercise-induced asthma as a result of swimming intervention **Pre vs. post-swim training in asthmatic children:** 1) Significant ↓ in asthma disability, medication, posture and body fat
Huang 1989	**Population:** 90 children with asthma **Study Design:** CT **Duration:** 1 year **Swim Intervention:** n=45 asthmatic children (females, n=12) underwent swimming training (stroke not reported) of 1h/session, 3 times/week after school hours **Comparison group:** n=45 non-participant children matched for age, gender and severity of illness	• Physical examination • Lung function (peak flow meter) • Clinical progress (via school absenteeism, emergency room visits, hospitalization, days requiring daily medication, days of wheezing)	**Pre vs. post-swimming in swimming group:** 1) Significantly ↑ lung function (PEF) by 65% and 63% at 6 m and 12 m, respectively (21% and 25% at 6 and 12 m in the control group) 2) Significantly ↓ asthma attacks, wheezing, days requiring medication, emergency hospital visits, hospitalization, absence from school **Swimming vs. controls post-intervention:** 1) Compared to controls, significantly better improvements were seen in asthma attacks, lung function, wheezing, days requiring medication, hospitalization, emergency visits and absence from school
Matsumoto 1999	**Population:** 16 children with severe asthma **Study Design:** RCT **Duration:** 6 weeks **Swim Intervention:** n=8, front crawl swimming in heated pool at 30°C, 30min with 10min rest after 15min, 6 days/week **Comparison group:** non-swimming controls (n=8)	• Aerobic capacity and HR (cycling and crawl tethered-swimming tests) • Exercise-induced bronchoconstriction (via the mean fall in FEV1 from pre-exercise value) • Blood lactate (lactate analyzer) • Histamine challenge test	**Swimming vs. controls post-intervention:** 1) Significantly ↑ mean workload at the lactate threshold on both the swimming and cycling ergometers in the swimming group vs. controls 2) No changes in mean maximal % fall in FEV1 by absolute load at either 100% or 175% of the lactate threshold 3) No changes in histamine test **Pre vs. post-swimming training in the swimming group:** 1) Swimming and cycling ergometers: Significantly ↓ mean maximal % fall in FEV1 in swimming ergometer at 175% of the lactate threshold on the relative load 2) Cycling ergometer: Absolute load significantly ↑ at both 100% and 175% of the lactate threshold

Varray 1991	**Population:** 14 atopic children with asthma **Study Design:** RCT Duration: 6 months **Swim Intervention:** n=7 (male: 6, female: 1, age: 11.4±1.5 years), Aerobic training: 3 months- participants swam for 10 minutes at 3 times of their own ventilatory threshold velocity. A session ran for an hour and there were two different sessions per week. High intensity training 3-6 months- consists of a series of 25 m crawls performed at maximal speed, repeated 6 times in one series, with 1 minute break in between. A session consisted of 2 series for a total of 12 25m crawls. 2 sessions per week. **Comparison group:** Not specified, assumed treatment as per normal with no further interventions (n=7, male: 6, female: 1, age: 11.4±1.8 years)	• VO_2max • Ventilatory threshold • HRmax • Lung function: FEV1, FVC, FEF25%-75% in litres and as % predicted	**Swimming vs. controls:** 1) Significant ↑ in VO_2max in the swim group vs. control. 2) Significant ↑ in ventilatory threshold in the swim group vs. control. 3) No significant difference in any measure of lung function between groups. 4) Parents reporting participants in the swimming group did not have any decrease in frequency of wheezing attacks or use of regular asthma medication.
Varray 1995	**Population:** 18 asthmatic children **Study Design:** RCT **Duration:** 3 months **Swim Intervention:** n=9 (male: 7, female: 2) age: 10.3±1.3 years), 2 supervised swimming sessions per week for a period of 3 months. Each session lasted 1 hour within which the children swam at least 3 times at their own ventilatory threshold velocity for 10 minutes. **Comparison group:** n=9, non-swimming usual care (male: 7, female: 2, age: 11.7±0.5 years)	• VO_2max • Ventilatory threshold • Resting pulmonary function, Rate of perceived dyspnoea	**Swimming vs. controls:** 1) Significant ↑ in VO_2max in the swim group vs. control. 2) Significant ↑ in ventilatory threshold in the swim group vs. control. 3) No significant difference in any measure of lung function between groups. 4) Rate of perceived dyspnoea ↓ after swim training
Wang and Hung 2009	**Population:** 30 children with mild, moderate, or severe persistent asthma **Study Design:** RCT **Duration:** 6 weeks **Swim Intervention:** n=15, swimming (front crawl/ backstroke) 3 x 50min sessions / week, 65% of HRmax, in a non-chlorinated pool **Comparison group:** non-swimming controls (n=15)	• Lung function (spirometry) • Clinical progress (peak expiratory flow and daily assessment of asthma severity)	**Pre vs. post-swimming training in the swimming group:** 1) Significantly improvement in FEV1, FEF50, FEF25-75 at 6 weeks **Swimming vs. controls post-intervention:** 1) No differences in FEV1, FEF50, FEF25-75 at 6 weeks 2) Significant ↑ PEF in swimming both at 3 and 6 weeks vs. controls 3) Significant improvement in asthma severity after the intervention only in the swimming group

Weisgerber 2003	**Population:** 8 children with moderate persistent asthma **Study Design:** RCT **Duration:** 5-6 weeks **Swim Intervention:** n=5, 2 times/week, 45min/session (front crawl/backstroke swimming) **Comparison group:** non-swimming controls (n=3)	• Pulmonary function (spirometry) • Asthma symptoms (questionnaire)	**Swimming vs. controls post-intervention:** 1) No changes in pulmonary function (i.e., PEF, FVC, FEV1, or FEF25-75) or asthma symptoms
Weisgerber 2008 Also: Weisgerber 2009	**Population:** 61 children with mild, moderate, or severe persistent asthma **Study Design:** RCT **Duration:** 9 weeks **Swim Intervention:** high-intensity swimming programme with 27 x 1 hour sessions. 30 mins standardised swimming instruction and 30 min of vigorous swimming consisting of 4 phases: interval training (12-15 min periods swim 20-80s full-speed drills of flutter-kicking, water jumping, introductory front crawl, introductory back stroke, then rest for 20–80s), endurance training, relay races, and water games. (n=35 age: 10.7±1.9 years) **Comparison group:** moderate-intensity activity golf programme 27 x 1-hr sessions.(n=26, age: 9.9±1.8 years)	• Fitness (VO_2max, Coopers 12 min walk/run test, exercise time, peak HR) • FEV1 % • Symptoms (questionnaires) • Urgent asthma visits	**Swimming vs. golf:** 1) VO_2max improved by 5% in the golf group vs -3.1% in the swim group, but this was not a statistically significant difference. 2) FEV1 % predicted was significantly greater in the swimming group vs. golf group. 3) No significant difference in the Coopers 12-minute walk-run test between swimming training and golf groups 4) No significant difference was found for symptoms between swimming and golf exercise groups 5) Five symptom exacerbations occurred during 700 person-sessions of the swimming programme (7.1 per 1000 sessions) and one symptom exacerbation occurred during 425 person-sessions of golf (2.4 per 1000 sessions) 6) No significant difference in urgent asthma physician visits between the swimming training and golf groups
Wicher 2010	**Population:** 71 children and adolescents with moderate asthma **Study Design:** RCT **Duration:** 12 weeks **Swim Intervention:** 60 minutes session x twice weekly classes. 2 levels swimming training according to previous experience: Level I (n = 26): adaptation to the water, breathing with full immersion, floating, swimming and basic diving, Level II (n = 4): children who had the skills described plus learning front and back crawl. (n=30, age: 10.4±3.1 years) **Comparison group:** non-swimming controls (n=31, age: 10.9±2.6 years)	• Spirometric assessment: FVC, FEV1, FEF 25-75% • Methacholine challenge test: provocative concentration of methacholine causing a 20% fall in FEV1 (PC20)	**Pre vs. post-swimming vs. control:** 1) Significant pre-post ↑ in PC20, maximal inspiratory pressure, and maximal expiratory pressure were found in the swimming group, with significant between group's changes in PC20. 2) No significant change in FVC, FEV1, FEF 25-75% for swimming training compared with control. 3) No participant was admitted to hospital for asthma attacks during in the "run in" or during the training period in either the swimming or control group.

Edlund 1986	**Population:** 23 boys and girls (females, n=9) **Study Design:** CT **Duration:** 12 weeks **Swim Intervention:** Swimming pool of 32°C to 35°C, 60min, 3 days / week, with intensities of 60-75% of HRmax in the first 5 weeks, progressively building up to 70-85% during the last 4 weeks (n =13) (swim stroke not provided) **Comparison group:** n=10 non-swimming controls	• VO_2peak, VE, VCO_2 and RER directly measured only in 12 participants (gas analysis); in 8 it was predicted (equation) • HR (ECG) • Pulmonary function (respirometer) • Clinical Analysis of the disease status	**Swimming vs. controls post-intervention:** 1) No significant differences in directly measured VO_2peak, VE any pulmonary function parameters 2) VO_2peak predicted from equations significantly ↑ in the swimmers but not controls 3) No significant differences in body mass 4) Significant improvements in clinical disease status only in the swimming group

INDIVIDUALS WITH HYPERTENSION

First Author	Methodology	Outcome Measures (Technique)	Findings
Chen 2010	**Population:** 23 participants, 7 of which with mild hypertension and 16 normotensive **Study Design:** Single group **Duration:** 1 year **Swim Intervention:** training (no swim stroke provided) started for all participants at the start of the 1st year of college and continued for one year (distance increased from 0 to 7km per session)	• BP (sphygmomanometer) • Glucose (method of glucose oxidase) and insulin (ELISA) • Anthropometric assessments	**Pre vs. post-swimming in total sample:** 1) Significant ↓ in fasting plasma glucose 2) No significant changes in DBP, BMI, body mass and insulin resistance **Normotensives vs. hypertensives post-intervention:** 1) Significant ↑ SBP in normotensives 2) Significant ↓ SBP and insulin resistance only in hypertensives 3) No significant changes in DBP and BMI
Mohr 2014 Also: Mohr 2015 Connoly 2016 Nordsborg 2015	**Population:** 83 premenopausal obese mildly hypertensive women **Study Design:** Quasi-RCT **Duration:** 15 weeks **Swim Interventions:** a) n=21, moderate-intensity swimming group with continuous front crawl for 1h with participants encouraged to swim as far as possible, b) n=21, high-intensity swimming group doing 6–10 30sec bouts of all-out front crawl swimming interspersed by 2 min of passive recovery **Comparison groups:** soccer (n=20) and controls (n=20)	• Performance via a 10min swimming test and a repeated sprint test and Yo-Yo fitness test, • HR (monitor) and SBP, DBP, MAP (automatic monitor) • OGTT, insulin, glucose and lipids (enzymatic kit), sICAM-1 and sVCAM-1 (ELISA) • Muscle samples from the medial part of the vastus lateralis muscle and the posterior (90% of samples) or anterior (10% of samples) part of the deltoideus muscle (biopsy), muscle glycogen, citrate synthase, 3-Hydroxyacyl-CoA dehydrogenase, complex i-v, phosphofructokinase protein expression	**High vs. moderate-intensity swimming vs. controls post-intervention:** 1) Significant ↑ in Yo-Yo fitness test in both swimming groups but not controls 2) Significant ↓ SBP in both swimming groups but not controls 3) No differences in HR, MAP and DBP 4) No differences in fasting plasma glucose and lipids 5) Significantly ↓ fasting plasma insulin, insulin sensitivity and sVCAM-1 only with high-intensity but not moderate-intensity or controls

		• Body composition (DEXA), waist-to-hip ratio and waist circumference; • BMC and BMD (DEXA), bone turnover markers (biomarkers)	6) Significantly ↓ sICAM-1 with high-intensity and controls but not moderate-intensity 7) Significantly ↑ citrate synthase in both muscle groups after both high and moderate intensity swimming, and after high intensity swimming was higher in deltoideus than in vastus lateralis 8) Significantly ↑ 3-Hydroxyacyl-CoA dehydrogenase in deltoideus after high and moderate intensity training, while in the vastus lateralis it increased only with high-intensity 9) Significantly ↑ complex I-V in deltoideus muscle after high and moderate intensity swimming but significantly ↑ muscle glycogen only after high-intensity swimming 10) Significant ↓ body mass, waist circumference, total fat mass and body fat in both swimming groups but not controls 11) Significantly ↓ hip circumference with moderate intensity but not high-intensity or controls **High vs. moderate-intensity swimming vs. soccer vs. controls post-intervention:** 1) Significantly ↑ total leg BMC, femoral shaft and trochanter BMD, and bone turnover biomarkers in soccer but none of the other groups 2) No changes in total leg BMD, total body BCM and BDM or pelvic and arm BCM and BDM
Silva 2009	**Population:** 46 individuals with mild and moderate hypertension **Study Design:** CT **Duration:** 10 weeks **Swim Intervention:** n=23, 3 weekly 50min front crawl swim sessions, stating at an intensity of 40% HRmax) **Comparison group:** non-swimming controls (n=23)	• BP every week for 10 weeks (automated monitor) • Body mass	**Pre vs. post-intervention in swimming group:** 1) Significant ↑ SBP (4.89 mmHg) and DBP (6.52 mmHg) **Swimming vs. controls post-intervention:** 1) No changes in body mass and BMI
Nualnim 2012	**Population:** 43 individuals with prehypertension and stage 1 hypertension (females, n=11) **Study Design:** Quasi-RCT (randomization was eliminated for those strongly objecting their allocation) **Duration:** 12 weeks	• VO_2peak (gas analysis) • Bilateral brachial and ankle BP (automated device) and carotid and femoral pulse-wave velocities (tonometry), 24h BP (ambulatory monitor),	**Swimming vs. controls post-intervention:** 1) No significant changes detected in VO_2peak 2) Significantly ↓ resting SBP, daytime SBP and carotid systolic pressure in swimming group only 3) Significantly ↑ carotid artery compliance, FMD, cardiovagal baroreflex sensitivity in swimming group only

	Swim Intervention: n=24, supervised 15-20 minutes/day, 3-4 days/week at 60-75% of HRmax) (swim stroke not provided) **Comparison group:** relaxation (n=19)	• SV, CO and FMD (ultrasound), carotid arterial compliance, cardiovagal baroreflex sensitivity (beat-to-beat BP) • Body composition (DEXA)	4) No significant changes in any other blood pressure and hemodynamic assessments 5) No significant changes detected in glucose, hemoglobin, cytokines, lipids and body composition 6) SV and CO data not reported
Tanaka 1997a Also: Tanaka 1997b	**Population:** 18 (female n=8) hypertensive patients with uncomplicated stage 1 or 2 hypertension **Study Design:** CT **Duration:** 10 weeks **Swim Intervention:** n=12, supervised swimming (front crawl), 60min/sessions, 3 days per week on alternate days at 60% of HRmax) **Comparison group:** non-swimming controls (n=6)	• Resting HR, BP, MAP • Casual forearm vascular resistance (plethysmography) resistance (plethysmography) • Lactate and RPE • Plasma and blood volume (Evans dilution method) • Glucose (hexokinase/glucose 6 phosphate dehydrogenase method), insulin (radioimmunoassay), lipids (enzymatic method) • Plasma epinephrine and norepinephrine (radioenzymatic technique), • Body composition (hydrostatic weighing), BMI, waist to hip ratio and circumference	**Swimming vs. controls post-intervention:** 1) Significant ↓ in resting and supine SBP in swimming group 2) No changes in resting DBP, supine DBP and casual forearm vascular resistance 3) Significant ↓ resting HR, RPE and blood lactate in swimming group 4) No changes in plasma and blood volume, catecholamines, glucose, insulin and lipids 5) No changes in body mass, lean body mass and body fat

INDIVIDUALS WITH OTHER CONDITIONS

First Author	Methodology	Outcome Measures (Technique)	Findings
Alkatan 2016a Also: Alkatan 2016b	**Population:** 48 sedentary middle-aged and older adults with OA, 40 completed the study **Study Design:** RCT **Duration:** 12 weeks **Swim Intervention:** n=20, front crawl/breaststroke swimming from 20min progressively up to 40-45min/day, 3 days/week, from 40-50% progressively up to 60-70% HRmax **Comparison group:** cycling (n=20)	• Fitness (6min walking test) • Heart rate • Brachial and ankle BP • Carotid-femoral pulse wave velocity (all the 3 above with automated vascular testing device) • Central systolic BP, pulse pressure • FMD and carotid arterial diameter (ultrasound) • Lipids, inflammatory and metabolic biomarkers • Body mass and composition (DEXA and circumferences) • Strength (isokinetic dynamometry)	**Swimming vs. cycling post-intervention:** 1) Significant ↑ in 6-min walking test and carotid artery compliance in both groups 2) Significantly ↑ FMD only in the swimming group 3) Significantly ↑ glycated hemoglobin and interleukin 6 in both groups 4) Significantly ↓ carotid-femoral pulse wave velocity, carotid artery stiffness index, carotid artery distensibility, body mass, waist and hip circumferences, visceral adiposity in both groups 5) Significantly ↑ left and right grip strength, isokinetic knee peak torque at 60° and 120° in both groups 6) No significant changes in BP, SBP, DBP, pulse pressure, HR, carotid intima media thickness, BMI lipids, glucose, and other cytokines, body fat % and lean body mass in either group

Casey and Emes 2011	**Population:** 28 adolescents with Down-syndrome (females, n=12) **Study Design:** RCT **Duration:** 12 weeks **Swim Intervention:** n=14, front crawl swimming, 3 times/ week, 1 hour/session **Comparison group:** non-swimming controls (n=14)	• Maximum phonation duration, initiation volume, mean expired airflow (all with a speech respiratory test)	**Swimming vs. controls post-intervention:** 1) No significant changes in any of the speech respiratory variables
Stephen 2013	**Population:** 89 Aboriginal children with tympanic membrane perforation **Study Design:** RCT **Duration:** 4 weeks **Swim Intervention:** n=41, 5 days/week, 45 min/session in a chlorinated pool (swim stroke not provided) **Comparison group:** non-swimming controls (n=48)	• Otoscopic signs of ear discharge in the canal/middle ear space (tympanometry, otoscopy and video otoscopy) • Respiratory bacteria (swab collection and microbiology)	**Swimming vs. controls post-intervention:** 1) 24 of 41 swimmers had ear discharge at 4 weeks compared with 32 of 48 non-swimmers 2) No significant changes in the microbiology of the nasopharynx or middle ear in swimmers or non-swimmers

Abbreviations. RCT: randomized controlled trial, HR: heart rate, HRmax: maximum heart rate, HRres: heart rate reserve, BP: blood pressure, SBP: systolic blood pressure, DBP: diastolic blood pressure, MAP: mean arterial pressure, BMI: body mass index, RPE: rate of perceived exertion, FEV1: forced expiratory volume in during the first second of forced breath, FVC: forced vital capacity, FEF50: forced expiratory flow at 50% of the forced vital capacity, FEF25-75: average forced expiratory flow during the mid (25 - 75%) portion of the forced vital capacity, PEF: peak expiratory flow, DEXA: dual energy x-ray absorptiometry, VO_2: oxygen uptake, LDL: low density lipoprotein, MRI: magnetic resonance imaging, CC16: Clara cell secretory protein, SP-D: surfactant protein D, RER: respiratory exchange ratio, RPE: rate of perceived exertion, ECG: electrocardiogram, FMD: flow mediate dilation, SV: stroke volume, CO: cardiac output, FMD: flow mediated dilation, BMC: bone mineral content, BMD: bone mineral density, OGTT: oral glucose tolerance test, sICAM-1: soluble intracellular adhesion molecule 1, sVCAM-1: soluble vascular cell adhesion molecule 1, VE: Minute ventilation.

Table 3.
The acute and chronic effects of cold water swimming

First Author	Methodology	Outcome Measures (Technique)	Findings
ACUTE PHYSIOLOGICAL RESPONSES TO COLD WATER SWIMMING			
Lombardi 2011	**Population:** 15 participants (females, n=2) never exposed previously to winter swimming **Study Design:** Single group **Intervention:** Non-competitively 150m swimming (stroke not provided) in water temperature of 6°C	• Haemoglobin and haematocrit, • Red blood cell count, white blood cell count and platelet count • Relative and absolute number of leucocyte subpopulations • Mean corpuscular haemoglobin • Mean corpuscular volume • Mean corpuscular haemoglobin concentration • All with an automated hematology system	**Day before swimming vs. post swimming:** 1) Significant ↑ in hemoglobin and hematocrit after swimming 2) Significant ↑ in both red and white cell count as well as platelet count 3) From relative number of leucocytes, only eosinophils ↑ significantly 4) From absolute number of leucocyte subpopulations: significant ↑ in absolute number of neutrophil granulocytes, lymphocytes and monocytes 5) 2.54% ↓ plasma volume (significance not reported) 6) No differences in mean corpuscular hemoglobin, volume or hemoglobin concentration
Siems and Brenke1992 Also: Siems 1994	**Population:** 10 healthy participants accustomed to winter swimming (1-11 years, mean age 40.5±12.3 years) and **Study Design:** CT **Intervention:** Participants assessed pre, during and post ~5-min cold water swimming (stroke not provided) **Comparison group:** 10 healthy controls with no winter swimming experience (mean age: 35.6±8.8 years)	• Erythrocytic level of oxidized glutathione • Erythrocytic level of oxidized glutathione / total glutathione ratio • Uric acid (determined as described by Bergmeyer method)	**Pre vs. post-swimming:** 1) Significant ↑ in both the erythrocytic level of oxidized glutathione and the erythrocytic level of oxidized glutathione / total glutathione ratio in during and post cold-water swimming only in swimmers 2) 1-h following the whole body cold stimulus, the uric acid levels were approx. half of the initial values, 141±69 μM (The uric acid level decreased within 1 h after cold exposure from 0.31 to 0.14 mmol/L. However, 24 h after the winter swimming, the plasma uric acid levels were back to the initial values. 3) The haematocrit values did not show significant differences between controls (40.8±2.7%) and winter swimmers (41.9±4.5%).

Siems 1999	**Population:** 36 healthy participants (23 male, 13 women) accustomed to winter swimming (2-11 years, mean age 36.1±11.8 years) **Study Design:** CT **Intervention:** Participants assessed pre, during and post ~5-min cold water swimming (stroke not provided). Water temperature 1-4°C, air temperature 1-5°C. **Comparison group:** 40 healthy controls (28 male, 12 women) with no winter swimming experience (mean age: 36.3±10.4 years)	• Reduced glutathione • Erythrocytic level of oxidized glutathione • Superoxide dismutase • Glutathione peroxidase • Catalase • Uric acid, glucose, potassium ions, plasma protein concentration, creatine kinase, γ-glutamyl transaferase, alkaline phosphatase, and aspartase aminotransferase measured before and after ice-bathing in winter swimmers (data not eligible here).	**Swimmers vs. non-swimmers:** 1) Baseline concentrations of reduced glutathione, and activities of erythrocyte superoxide dismutase and catalase higher in winter swimmers compared to non-swimming controls.
Tipton 1999	**Population:** 10 young healthy competent swimmers (females, n=1), just above average fitness levels but never exposed to winter swimming **Study Design:** Single group with crossover **Intervention:** Self-paced breaststroke while wearing swim wear at: a) 25°C, b) 18°C and c) 10°C in a variable speed swimming flume according to the request of swimmers	• VO_2 and VCO_2 (mass spectrometer) • HR (ECG) • Expiratory volume (mass flow regulator) • Respiratory frequency, inspiratory volume, tidal volume (ventilatory module) • Hand grip strength • Rectal temperature (thermistor)	**Swimming in 25°C vs. 18°C vs. 10°C:** 1) Significant progressive ↑ in mean VO_2 and HR with decreasing water temperature 2) Significant progressive ↑ in inspiratory volume and respiratory frequency with decreasing water temperature 3) Hyperventilation with lower water temperature 4) Swimming efficiency significantly ↓ at 10°C 5) Grip strength significantly ↓ at 18°C and 10°C but not 25°C 6) Rectal temperature significantly ↓ at 10°C vs. both 25°C vs. 18°C
Zenner 1980	**Population:** 27 members of a cold-swimming club **Study Design:** Single group **Intervention:** Participants assessed: a) indoors prior to swimming, b) after 10sec been immersed in cold water, c) after 60sec vigorous swim in cold water (stroke not provided)	• HR (ECG) • Blood pressure	**Pre vs. post-swimming:** 1) No significant rhythm and cardiac disturbances were detected 2) ↑ Blood pressure post-swimming vs. baseline (SBP: from 132±4 to 181±6, and DBP: from 80±2 to 86±4 mmHg, significance not reported) 3) ↓ Blood pressure 4min post-swimming vs. immediately post-swimming (SBP 4min post-swimming: 151±5, and DBP4min post-swimming: 84±4 mmHg, significance not reported).

CHRONIC PHYSIOLOGICAL ADAPTATIONS TO COLD WATER SWIMMING			
First Author	Methodology	Outcome Measures (Technique)	Findings
Hirvonen 2002	**Population:** 25 regular winter swimmers (18 females and 7 males, mean age: 55.1 years) **Study design:** CT **Intervention:** Cold water swim took on average 5-6 times a week during one winter swimming season (October-May) **Comparison group:** control group of 11 non-swimmers (8 females and 3 males, mean age: 53.8 years)	• Serum catecholamines, serotonin and their metabolites as well as β-endorphin • SBP and DBP	**Pre vs. post-winter swimming season vs. controls:** 1) During the winter the mean epinephrine and norepinephrine concentration in plasma dropped in winter swimmers and control groups, with no statistically significant between group differences. 2) Dopamine was found in only three plasma samples. Its metabolite homovanillic acid did not vary during the winter and no between group differences. 3) β-endorphin plasma concentrations stayed on the same level throughout the season and did not show any differences between the groups 4) Plasma serotonin were not significantly different between both groups (~50% decrease in both groups during winter) 5) Significant ↓ Mean SBP in winter swimmers, no significant change in controls. But no significant between group differences in SBP or within and between group changes in DBP.
Hermanussen 1995	**Population:** 11 healthy students, five females and six males, age 24 to 29 years, and their teachers. **Study Design:** CT **Intervention:** regular winter swimming for almost 3 months. Water temperature ranging from 6.8°C to 2°C and 2 to 10min but these varied quite considerable amongst individuals and were performed according to their mood in every session (stroke not provided) **Comparison group:** non-swimming controls	• Insulin (radioimmunoassay) • Glucose (hexokinase method) • Endocrine hormones (commercial kits) • Cortisol and GH (radioimmunoassays), Luteinizing hormone, follicle stimulating hormone, TSH and prolactine serum levels (automated method)	**Pre vs. post-swimming responses at baseline and post intervention:** 1) Insulin significantly ↓ throughout the swimming session post intervention (but not at baseline) 2) Glucose significantly ↑ throughout the swimming session only at baseline (but not post intervention) 3) Post intervention (but not at baseline) cortisol significantly ↑ during the first 30min of swimming and then significant ↓ from the 30th to the 60th min of swimming 4) Both at baseline and post intervention TSH significantly ↑ during the first 30min of swimming and then significant ↓ from the 30th to the 60th min of swimming 5) Prolactin significantly ↓ throughout the total length of swimming only at baseline

			6) No changes in GH, luteinizing hormone, follicle stimulating hormone were detected neither at 30min or 60min of swimming both at baseline or post intervention **Pre vs. post-intervention in swimmers vs. controls:** 1) Significantly ↑ in insulin, prolactin and follicle stimulating hormone as a result of winter swimming only in swimmers
Huttunen 2001	**Population:** Healthy winter swimmers **Study Design:** Single group **Intervention:** Acute cold water immersion in healthy winter swimmers at the beginning of the winter swimming period in the autumn and after regular swimming for 1-3 months (stroke not provided).. River water temperature was 10°C at the beginning and 4°C after one and three months.	• Plasma catecholamine levels (epinephrine and norepinephrine	**Pre vs. post-winter swimming season:** 1) Epinephrine and norepinephrine levels determined before ~36 a cold water immersion test ↓ with the winter swimming period for 1 month 2) The test immersion significantly ↑ norepinephrine levels. Plasma epinephrine and serum cortisol levels were increased or decreased by the immersion. 3) After 1 month's swimming the test immersion to 4°C ↑ noradrenaline to a similar level than the immersion to 10°C at the beginning. 4) Regularly practiced winter swimming for three months led to ↓ catecholamine levels measured immediately after the test immersion
Lubkowska 2013	**Population:** 15 healthy men, aged 23±1.47 years, with normal bodyweight (BMI 23.8±2.92 kg/m^2), **Study Design:** Single group **Swimming intervention:** participants swam in a lake, on average 2-3 times a week for a prolonged period of 5 months, from November to March. Each immersion in water took from 2-5 min, covered the whole body, excluding the head. The mean water temperature ranged from 12-15°C to 0-7°C from the beginning to the end of the study.	• Red blood cells, haemoglobin; haematocrit, mean corpuscular • Volume, mean corpuscular haemoglobin, mean corpuscular haemoglobin concentration, red blood cell distribution width, white blood cells, lymphocytes, monocytes, granulocytes, thrombocytes; • SBP and DBP, diastolic blood pressure • 8-isoprostane in plasma, reduced glutathione, erythrocytic level of oxidized glutathione, total oxidant status, and total antioxidant status • Components of the antioxidant system: superoxide dismutase, catalase, glutathione peroxidase, glutathione reductase, and glutathione S-transferase. • Body mass, BMI, body composition (via bioelectrical impedance)	**Pre vs. post-winter swimming season:** 1) Significant pre-post-winter season ↓ haemoglobin concentration (19% drop), the number of red blood cells (13% drop), the haematocrit index (20%) and mean corpuscular volume of red blood cell, and the percentage of monocytes. 2) Significant pre-post-winter season ↑ and the percentage of granulocytes. 3) Significantly ↑ SBP, but not DBP before and after winter training season. 4) Post-winter swimming season, significant ↓ in resting levels of 8-isoprostane in plasma and oxidized glutathione, with resulting ↓ in glutathione total, oxidized glutathione: reduced glutathione ratio ↑ two times. Significant ↑ in superoxide dismutase, catalase, and glutathione reductase activity at the end of the season. 5) There was a significant ↓ in the activity of glutathione peroxidase. 6) There were no changes in glutathione S-transferase activity.

			7) Responses to whole body cryostimulation was lower after the winter swimming season, with no changes in 8-8-isoprostane in plasma concentration, superoxide dismutase, and glutathione S-transferase, and a lower total antioxidant status reduction compared to significant changes in these stress markers to whole body cryostimualtion before winter swimming season. 8) No significant changes in anthropometric characteristics or body composition of the participants over the winter season.
Gibas-Dorna 2016	**Population:** 30 members (females, n=14) of a winter swimming club training with at least 2 years of outdoor swimming and 11 controls **Study Design:** CT **Intervention:** 7 months swimming (stroke not provided) in cold water (range: 1°C to 9.5°C) at least twice a week for up to 15min without any protection **Comparison Group:** non-swimming group with participants never participated in any type of cold exposure	• Body composition (bioelectrical impedance) • Glucose (Reflotron system) • Insulin (radioimmunoassay) and Insulin sensitivity	**Pre vs. post intervention in swimmers:** 1) No differences in any body composition parameter in swimmers 2) Significant ↑ in insulin sensitivity in the middle of the training period vs. baseline 3) Significant ↓ in insulin secretion and resistance in the middle of the training period vs. baseline **Pre vs. post-intervention in male vs. female swimmers:** 1) Significant ↓ in fat-free mass, total body water and muscle mass in women but not men

APPENDIX A

Eligibility criteria, methodology, search strategy

Criteria for considering studies for this review

Inclusion Criteria

1. Study design: randomised controlled trials, quasi-randomised controlled trials, and controlled trials.
2. Types of participants: we included studies only in humans and specifically pregnant women, infants, children and adolescents, as well as adults of any age. We included both healthy participants as well as those with long-term conditions.
3. Studies that investigated either the acute physiological responses or chronic physiological adaptations of swimming, or outcome measures that concerned any physiological or health-related parameters.
4. We included only full publications and did not exclude based on language.

Exclusion Criteria

Studies were excluded if they investigated:

1. Elite, competitive and trained swimmers (professional, national and international, varsity and college, or if the authors defined the population included as elite) or triathletes or a mixed athletic population where the effects of swimming on physiological outcomes could not be separated.
2. Non physiological-related variables (e.g. stroke rate, speed, mood, etc.).
3. Utilised water-based physical activities (e.g. water-based aerobic activities, cycling on a cycling ergometer while immersed, water polo) or hydrotherapy or aquatic interventions where the effects of swimming could not be studied separately.
4. A swimming intervention combined with a drug or dietary or other physical activities intervention, where the effects of swimming could not be separated.
5. Scuba-diving, breath-holding and water-immersion activities.
6. Animal studies.

Data sources to be searched: We searched the following databases to identify eligible studies: PubMed, EMBASE, and Cochrane Central Register of Controlled Trials (CENTRAL) (via the Cochrane Library, Issue 2, 2015). We also screened references in relevant reviews and in published eligible studies.

Search strategy: A search algorithm was developed for Pubmed (see below) and was modified for CENTRAL and EMBASE.

Pubmed search strategy

Search	Query	Items found
27	Search (25 NOT 26)	5935
26	Search (animals[MeSH Terms]) NOT humans[MeSH Terms]	4301329
25	Search (8 AND 25)	15025
24	Search (9 OR 10 OR 11 OR 12 OR 13 OR 14 OR 15 OR 16 OR 17 OR 18 OR 19 OR 20 OR 21 OR 22 OR 23)	1815961
23	Search physiolog* benefit*[Title/Abstract]	65154

22	Search long-term adaptation*[Title/Abstract]	845
21	Search long-term effect*[Title/Abstract]	32949
20	Search long-term response*[Title/Abstract]	1828
19	Search short-term effect*[Title/Abstract]	7730
18	Search short-term response*[Title/Abstract]	973
17	Search acute response*[Title/Abstract]	2261
16	Search acute effect*[Title/Abstract]	13413
15	Search chronic adaptation*[Title/Abstract]	184
14	Search physiolog* effect*[Title/Abstract]	1315641
13	Search chronic response*[Title/Abstract]	339
12	Search chronic effect*[Title/Abstract]	4658
11	Search physiolog* response*[Title/Abstract]	713668
10	Search physiolog* adaptation*[Title/Abstract]	75601
9	Search training effects[Title/Abstract]	1592
8	Search (1 OR 2 OR 5 OR 6 OR 7)	47344
7	Search aquatic sport*[Title/Abstract]	56
6	Search aquatic exercise*[Title/Abstract]	247
5	Search (3 AND 4)	6286
4	Search exercise*[Title/Abstract]	239936
3	Search (water*[Title/Abstract]) OR aquatic*[Title/Abstract]	672775
2	Search swim*[Title/Abstract]	32301
1	Search swimming[MeSH Terms]	21270

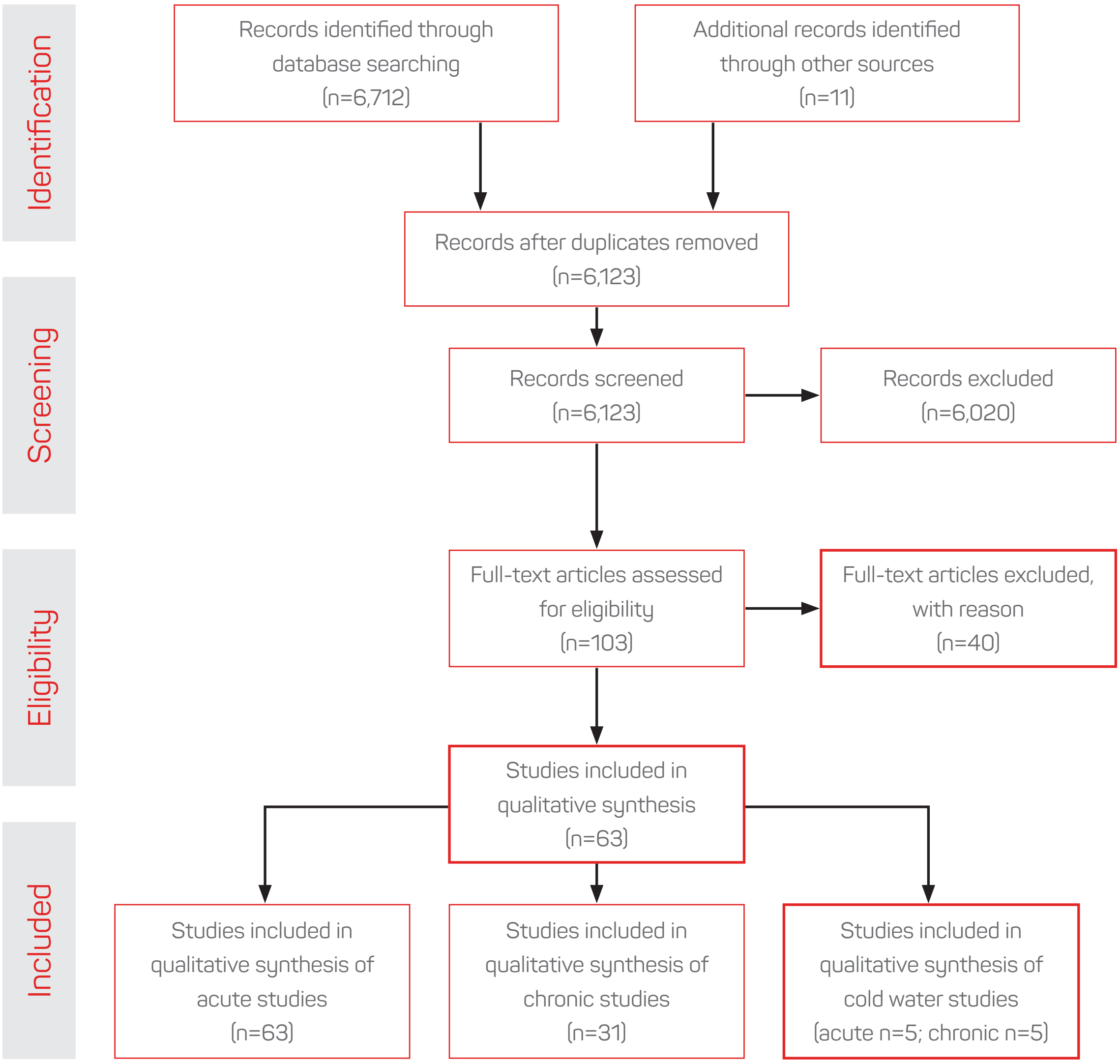
Study selection: The results from the searches described above were merged and duplicate records of the same report were removed. The titles and abstracts were examined to remove obviously irrelevant reports. Two authors independently screened and assessed the records for eligibility. Disagreements on study eligibility were resolved through consensus. Full-text articles of potentially relevant reports were retrieved and multiple reports of the same study were linked together. Full-text reports were examined for compliance of studies with the eligibility criteria. A list of studies that were close to inclusion but after further inspection did not meet the criteria were recorded in the 'Reasons for exclusion of studies' table. Non-English language trials were included and these trials were translated, where necessary, so that eligibility could be assessed and subsequently data extracted.

Data extraction: A checklist of items was developed to include the source of report; confirmation of eligibility or reason for exclusion; methods such as study design, total duration, sequence generation, allocation sequence concealment, blinding, and other sources of bias; participant information such as total numbers, demographic information; and date of study; intervention details; for each outcome of interest the definition, unit of measurement and scales, time points of assessments, results including number of participants allocated to groups, sample size, missing data, summary of data for each group, and key conclusions. Two authors (IL, GM) independently extracted the data and any conflicts not due to extractor error were resolved through consensus. Multiple publications for the same trial were collated and the most complete report (that is the one with the outcomes most relevant to the review or the most recwent outcomes) was used as the primary reference. We summarised the data collected from the reports in the characteristics of studies tables (Table 1, 2, and 3).

Risk of bias assessment of articles: The Cochrane Collaboration's 'risk of bias' tool was used to assess possible sources of bias in the included reports (Higgins 2011). The assessment of risk of bias included an investigation of biases in domains such as sequence generation, allocation concealment, blinding, incomplete outcome data, selective reporting bias, and 'other issues'. Two authors (IL, GM) assessed the risk of bias, and conflicts not due to assessor error were resolved by consensus. If there was evidence of a large risk of bias the findings will be interpreted cautiously. The assessment of risk of bias was displayed in a 'risk of bias' graphs (Figures 3 and 4, and Appendix D and E.

APPENDIX B

PRISMA Flow of studies



From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097.

APPENDIX C

Reasons for exclusion of studies table

Excluded study	Reason for exclusion
Altintas 2003	Available in abstract form only
Dugue et al. 1998	Available in abstract form only
Niedoszytko 2009	Available in abstract form only
Wang and Hart 2005	Did not include physiological variables
Dias et al. 2013	Did not include physiological variables
Garcia et al. 2011	Did not include physiological variables
Rushall et al.2012	Did not include physiological variables
Martin et al. 1987	Effects of swimming could not be isolated
Cade et al. 1991	Effects of swimming could not be isolated (dietary intervention)
Lamb et al. 1990	Effects of swimming could not be isolated (dietary intervention)
Dugue et al. 2000	Effects of swimming could not be isolated (from sauna)
Svenonius 1983	Effects of swimming could not be isolated (swimming + other exercise)
Noland et al. 2001	Included collegiate swimmers
Valentine and Evans 2001	Included collegiate swimmers
Greenwood et al. 2008	Included collegiate swimmers
Fitts et al. 1989	Included collegiate swimmers
Skorski et al. 2012	Included competitive swimmers
Rodríguez et al. 2016	Included competitive swimmers
Pelarigo et al. 2016	Included elite swimmers
Deligiannis et al. 1993	Included elite swimmers
Houston et al. 1981	Included elite swimmers
Mougios et al. 1993	Included elite swimmers
Arnett et al. 2002	Included elite swimmers
Fu et al. 2002	Included elite swimmers
Bilberg et al. 2005	It did not investigate effects of swimming (aqua exercise)
Tomas-Carus et al. 2008	It did not investigate effects of swimming (aqua exercise)
Teleglow et al. 2016	It did not investigate effects of swimming (bathing)
McMurray et al. 1994	It did not investigate effects of swimming (cycling underwater)
McMurray et al. 1993	It did not investigate effects of swimming (cycling underwater)
Bermingham et al. 2004	It did not investigate effects of swimming (cycling underwater)
Paulev et al. 1990	It did not investigate effects of swimming (diving)
Dugue and Leppanen 2005	It did not investigate effects of swimming (immersion)
Smolander et al. 2009	It did not investigate effects of swimming (immersion)
Sutkowy et al. 2015	It did not investigate effects of swimming (immersion)
Fujimoto et al. 2016	It did not investigate effects of swimming (immersion)
Herstgard et al 1992	It did not investigate effects of swimming (play)
Huttunen et al.2004	Winter swimming improves general wellbeing
Aggeloussi et al. 2012	Wrong study design, cross-sectional study
Ozer et al. 2007	Wrong study design, cross-sectional study
Lotgering et al. 1996	Wrong study design, review

APPENDIX D

Risk of bias summary for acute studies: review authors' judgements about each risk of bias item for each included study.

	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (performance bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)	Other bias
Atsumi 2008	–	–	–	–	+	?	+
Boning 1988	–	–	–	–	+	?	–
Bucking and Krey 1986	–	–	–	–	+	?	+
Dixon and Faulkner 1971	–	–	–	–	+	?	+
Fletcher 1979	–	–	–	–	+	?	+
Galbo 1979	–	–	–	–	+	?	+
Grace 1987	–	–	–	–	+	?	+
Heigenhausen 1977	–	–	–	–	+	?	+
Holmer 1972	–	–	–	–	+	?	+
Holmer and Bergh 1974	–	–	–	–	+	?	+
Lakin 2013	–	–	–	–	+	?	+
Lehmann and Samek 1990	–	–	–	–	+	?	+
Madger 1981	–	–	–	–	+	?	+
McMurray 1991	–	–	–	–	–	?	+
Meyer and Bucking 2004	–	–	–	–	+	?	+
Morgan 1989	?	?	–	–	+	?	+
Sasaki 1993	–	–	–	–	+	?	–
Schmid 2007	–	–	–	–	+	?	+
Spinnewijn 1996	–	–	–	–	–	?	+
Ueda 1995	–	–	–	–	+	?	–
Viti 1989	–	–	–	–	+	?	–
Weiss 1988	–	–	–	–	+	?	+

APPENDIX E

Risk of bias summary for chronic studies: review authors' judgements about each risk of bias item for each included study.

	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (performance bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)	Other bias
Alkatan 2016	+	+	−	+	+	−	+
Arandelović 2007	?	?	−	−	−	?	+
Bemanian 2009	−	−	−	−	+	?	−
Bielec 2013	−	−	−	−	+	?	+
Casey and Emes 2011	?	?	−	−	+	?	+
Celik 2013	+	−	−	−	+	?	+
Chen 2010	−	−	−	−	+	?	−
Cox 2006	+	+	−	−	+	?	+
Edlund 1986	−	−	−	−	−	?	+
Fernández-Luna 2013	−	−	−	−	+	?	+
Fitch 1976	−	−	−	−	+	?	+
Gonenc 2000	−	−	−	−	+	?	−
Huang 1989	−	−	−	−	−	?	+
Lavin 2015	?	?	−	−	+	?	+
Lu and Wang 2014	+	+	−	−	+	?	+
Lynch 2007	−	−	−	−	−	?	+
Magel 1975	−	−	−	−	+	?	+
Matsumoto 1999	?	?	−	−	+	?	+
Mohr 2014	−	−	−	−	+	?	+
Nualnim 2012	?	?	−	+	+	?	+
Obert 1996	−	−	−	−	+	?	+
Silva 2009	−	−	−	−	+	?	+
Soultanakis 2012	?	?	−	−	+	?	+
Stephen 2013	+	+	−	+	+	+	+
Tanaka 1997	?	?	−	+	+	?	−
Varray 1991	?	?	−	−	+	?	+
Varray 1995	+	?	−	−	+	?	+
Wang and Hung 2009	?	?	−	−	+	?	+
Weisgerber 2003	+	−	−	−	−	?	+
Weisgerber 2008	+	+	−	−	−	?	+
Wicher 2010	?	?	−	−	−	?	+

Chapter 4

The wellbeing benefits of swimming to communities: a literature review

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Key words:

swimming
aquatic exercise
community
wellbeing

Introduction

It is acknowledged that a critical strategy in the fight to improve population health and wellbeing is to focus on communities (Edwards, 2015). This is of particular relevance when considering social determinants of health and community health disparities (Marmot and Bell, 2012; WHO, 2017). Indeed, the complex and multi-faceted nature of community wellbeing has been implicated in the relative under-performance of individual-oriented strategies in reducing health inequalities (Edwards, 2015). The contention here is that many traditional health promotion approaches have been overly reductionist in nature, focussing upon the development of replicable programmes, aimed at individual outcomes across (notionally) homogenous populations, thereby obfuscating the representativeness of the community setting (Glasgow et al., 1999). As an alternative, approaches that operate at the community level capitalising upon, or further developing, the pre-existing social and human capital of a community, as well as its immanent organisational resources, may be used as leverage to identify and solve collective problems, and ameliorate wellbeing (Wendel et al., 2009).

Central to this proposition is the notion of community capacity (Laverack, 2006). In general terms, community capacity is defined as the *"activities, resources and support that strengthen the skills, abilities and confidence of people and community groups to take effective action and leading roles in the development of communities"* (Skinner, 2017). Labonte and Laverack (2001, p. 112) further conceptualise it as a space which circumscribes *"elements of peoples' day-to-day relationships, conditioned and constrained by economic and political practices, that are important determinants of the quality of their lives, and of communities' healthy functioning"*. As such, it is both an antecedent requirement for supporting community health and wellbeing, and the end-product of community-level interventions (Edwards, 2015; Wendel et al., 2009).

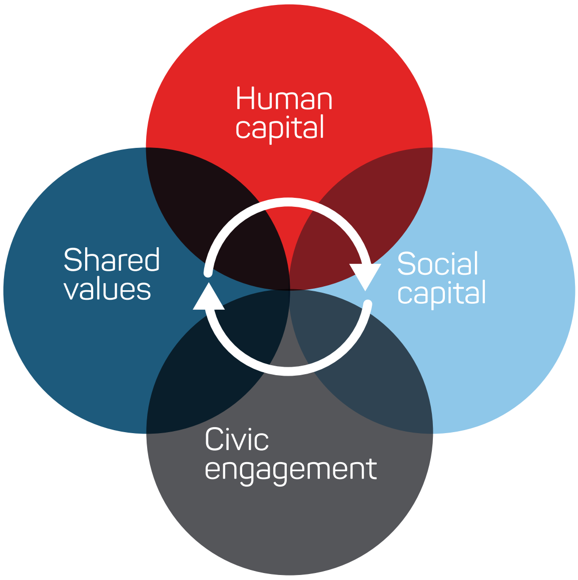
The role of sport as a vehicle for the promotion of physical, mental and social health within communities is increasingly advocated (Donaldson and Finch, 2012). Development through sport utilises sporting participation as a means of facilitating individual and societal progress (Berg et al., 2016). Indeed, sport, as a critical constituent of community and social development programmes, has been demonstrated to strengthen education, improve public health, address community safety, promote inter-cultural exchange and augment social cohesion/inclusion (Edwards, 2015). The intent of this chapter therefore is to consider the efficacy of swimming, as a community based sport, in contributing to community capacity.

Community Capacity

The concept of community capacity has been of interest across a diverse range of disciplines, it is not the sole remit of health and wellbeing. Nonetheless, Wendel et al. (2009) note that community capacity is intimately linked to The World Health Organisation's (WHO) expanded definition of health that acknowledges the criticality of controlling health determinants, and incorporates social and personal resources in addition to physical capacities.

As an evolving construct, there has been significant research endeavour aiming to develop or define the key characteristics or criteria of community capacity. This chapter will use the work of Wendel et al. (2009), who have described a number of dimensions of community capacity that represent the greatest degree of consensus across researchers. These dimensions have been used to inform the theoretical framework for this chapter (Figure 1), and will be reflected on in turn, specifically considering how swimming may influence each one.

Figure 1:
Key dimensions of community capacity (based on Wendel et al., 2009)



1. Human Capital

Human capital refers to the range of knowledge, resources, skills and experiences possessed by an individual or a community that is of inherent value. Swimming offers the community opportunity to develop significant human capital; perhaps most important is the ability to swim unaided, and be safe around pools, floods and open water. The Royal Life Saving Society (2017) notes that one person drowns every 20 hours in the UK, and many more experience significant morbidity as a result of near-drowning. Globally, drowning is the third leading cause of unintentional death, with an estimated 372,000 deaths worldwide (WHO, 2014). Whilst the incidence of drowning is much greater in low and middle income countries, it still remains a key public concern for developed countries, especially given the widespread promotion of aquatic based recreational activities and the increasing number of immigrants who originate from countries without a water safety culture (Berg et al., 2016). In the United States (US) there is racial disparity apparent in drowning rates, with significantly higher incidence amongst black children than white children of the same age range (Centers for Disease Control and Prevention, 2012). Berg et al. (2016) suggest that long-standing discriminatory practices have created a cultural norm within certain ethnic communities that water is treacherous and is to be avoided at all costs.

Research suggests that approximately 85% of morbidity and mortality associated with drowning could be prevented if better preventative measures, such as lifeguard availability and teaching children to swim, were instituted (Branche and Stewart, 2001; WHO, 2014). Consequently, The World Health Organisation have acknowledged the imperative to teach school-age children basic swimming, water safety and rescue skills, and to train bystanders in safe rescue and resuscitation (WHO, 2014). In the UK, this is acknowledged within the Scottish Swimming levels and the National Curriculum key stage requirements, with the ability to swim 25 metres unaided by the end of Key Stage 2 a governmental Key Performance Indicator (Bullough et al., 2015). Swimming organisations make a considerable contribution to community safety via their 'learn to swim' programmes (Tower et al., 2014). The value that community members place on such skills (and access to training and facilities) is evident from research. Specifically, swimming is conceptualised not just as a tool to promote physical activity, but also an essential life-skill: *"Swimming is not an option for my kids. They will swim, they will take lessons, they will know how to swim. And you know, ballet is an option, and soccer is an option, but swimming you must do..."* (DeLuca, 2016, p.267).

DeLuca (2016) notes that this parental mandate for children to learn to swim is a characteristic common amongst the upper-middle-class, and illustrates the pervasive structural regimes of power and privilege that persist within certain communities, and which facilitate some children to better develop swimming and life-saving competencies. As such, there is increasing interest in designing community swim programmes targeted at disadvantaged or under-represented sectors of local populations (Berg et al., 2016). Sustainable community programmes are best delivered via multi-agential collaborations in order to accommodate complex socio-political and socio-cultural contexts, as illustrated in Case Study 1.

Case Study 1

A multi-agential community sport development case study of swimming and drowning (Berg et al., 2016)

(The following case study describes one proposal for 'Memphis Swims Now', a community based programme designed in response to the fatal drowning of two Black youths in municipal pools)

The focus of the programme was not on elite or competitive swimming, rather swimming as a basic life skill, and as an opportunity to interact with other young people in a safe and sociable environment. The programme was to be delivered in a centrally-located pool to minimise travel constraints. A local children's hospital volunteered additional transportation. The Parks and Recreation department employed Black swimming instructors to ensure that coaches shared the same ethnic background as the majority of the participants. A local faith-based organisation offered to support the marketing of the programme. Whilst word-of-mouth promotion was felt to be a particularly effective way of disseminating information, it was also believed that parents and guardians would be more open to the programme given their pre-established trust in the faith organisation. The programme designers recognised the critical role that parents/guardians would play in the youths' willingness to try swimming as a new activity.

Social support and interaction were the key features of the programme intended to ensure retention of the participants. The coaches would offer personalised instruction to each swimmer based upon an initial assessment. Attendance and application would be awarded in an informal ceremony involving food and music at the mid-way and endpoint of the programme. Family and friends would be invited to celebrate the successes, with the intention that this would constitute further social reinforcement. Journalists would also be invited to profile 'Memphis Swims Now' in the hope of transforming the cultural associations Black residents had previously formed with regards open water and swimming. A monthly newsletter would also be created detailing the programme's history, the benefits of swimming etcetera.

A final element of the programme was to ensure that there was a dedicated time for unstructured play. This component was deemed essential in avoiding boredom with swimming drills, but also an opportunity to practice swimming skills in a fun and sociable way, fostering stronger friendships with other participants.

Human capital also refers to the knowledge, skills, attitudes and competence requisite for citizenship and work-related activities (Lawson, 2005). Swimming is implicated in improving youth development and enabling educational success, thereby contributing to human capital development (Hendrickx et al., 2016). These contributions may be especially salient for marginalised or disenfranchised groups (Lawson, 2005). In a systematic review of evidence that swimming pool attendance could improve health and wellbeing in remote Aboriginal communities in Australia, Hendrickx et al. (2016) also explored the wider community benefits such as school attendance. Of the nine studies included, a number involved community swimming pools that operated a 'no-school-no-pool' policy. One study demonstrated a statistically significant improvement in school attendance rates, but only in one of the two community pools studied (Lehmann et al., 2003). The other studies presented anecdotal reports that 'no-school-no-pool' policies could be effective, but did not provide significant data (Hendrickx et al., 2016).

Studies have also demonstrated that membership of a swim club offers opportunities that extend far beyond the acquisition of technical skills and improving cardiovascular fitness; membership can promote children's social learning and enculturation (Light, 2010; Light et al., 2013). Given that swimming is the most popular mass participation sport in the United Kingdom (UK) - 2.52 million now swim once a week, and nearly 164,000 are members of swimming clubs – the potential to shape the development of future community citizens is significant (Sport England, 2016). Light (2010) conducted a three month ethnographic study within a swimming club in Australia, focusing on the social, personal and cultural development of 9-12 year old members. Results demonstrated that the social connections and friendships formed as a consequence of swim club membership were significant contributors to enjoyment and retention, and were likely to be more important and more intimate than friendships formed elsewhere. Interviews of parents and coaches described the value of swim club membership in terms of developing values and traits necessary for life in the adult world, including personal discipline, goal-setting, social skills, a healthy level of self-esteem and an emergent sense of personal identity. Indeed, the authors acknowledge the children's experiences of enculturation into the language, customs, values and beliefs of the swimming club parallels the ways in which they learn to become adult members of the community.

In the UK, the aquatic industry is characterised by a number of delivery models including private enterprises, charitable organisations, community swim clubs and local authorities (Melville, 2010). For individuals involved within these industries, whether employed or on a volunteer basis, there is opportunity to develop wide-ranging skills that may also be a valuable, transferable, capacity-enhancing asset within the community (Wendel et al., 2009). For example, Swim England offers safeguarding, management, leadership and positive behaviour training, as well as conventional coaching (ASA, 2017). Such training is of value in terms of 'giving back' to the club and wider community, but also for gaining new skills and qualifications on an individual basis. Burgham and Downward (2005) suggest that linking skill acquisition to broader, recognised qualifications (potentially via collaboration with local further education colleges) may be a productive way to increase volunteering. In a study of 23 different community sports clubs (including swimming), the core competencies of volunteer members were identified as extending well beyond the cognitive, to include emotional intelligence and social intelligence (Balduck et al., 2010). Such traits, the authors note, are associated with charismatic leadership that potentially inspires motivation, commitment and a positive attitude to development.

Summary statement: Community capacity is enhanced by the development of human capital in terms of aquatic skills, a culture of water safety and, potentially, a range of transferable life-skills that are associated with swimming participation. These skills are highly valued by community stakeholders. Such human capital however, is highly influenced by a number of demographic factors, not least of all ethnicity and race. Programmes aiming to engender this form of human capital should be attentive to the socio-cultural and socio-political characteristics of the community.

2. Social Capital

The concept of social capital is generally believed to be a productive lens through which to observe how the social networks developed through communities might become catalysts for more positive identities and lifestyles (Skinner, 2006). Historically, public swimming pools have provided an important space where community members have attended for recreation, socialisation and participation in the public life of that community (Wiltse, 2007). Wiltse (2013) describes the community swimming pool as a barometer of community commitment to civic life. For example, he states that construction of new pools and high attendance rates are indicative of flourishing civic life, whilst pool closures and dwindling attendance represent the converse. The intimacy of the aquatic environment promotes a form of social interaction that has the potential to engender highly personal and social bonds. These networks of relationships may subsequently confer certain benefits on individuals, communities and societies (Edwards, 2015).

The term 'social capital' was first used by Hanifan to describe *"those tangible assets that count for most in the daily lives of people: namely goodwill, fellowship, sympathy and social intercourse among the individuals and families who make up a social unit"* (Hanifan, 1916 cited by Putnam, 2001, p.19). Numerous conceptualisations of social capital have subsequently been proposed, but for the purposes of this chapter the following definition, which attends to social capital as an attribute of the individual and the collective (Villalonga-Olives and Kawachi, 2015), and an opportunity to improve wellbeing, empowerment, trust, reciprocity, solidarity and community connectedness, will be used:

"... a quantity and/or quality of resource that an actor (individual or group or community) can access; or a resource that is located in social networks. The former emphasises the utility of social resources and the latter emphasises the utility of network characteristics. Implicit in definitions of social capital is its ability to **generate positive outcomes** *through shared* **trust, norms and values, benefits secured by membership in social networks;** *and the desirability of* **collective understanding and action***"* (Meikle-Law, 2006, p.55, emphasis added).

Social capital is significant as communities demonstrating high levels are more likely to be healthier, happier, safer, more resilient and have higher levels of employment (Delaney and Keaney, 2005; Skinner et al., 2008). Social capital is of particular importance in economically deprived communities as it may offer opportunities to solve problems in a more cost-effective fashion, or even without recourse to expenditure (Delaney and Keaney, 2005). Sport is believed to play an important part in the generation of social capital – it is invariably a social activity that creates networks that extend beyond the participants themselves, for example parents, volunteers and supporters (Putnam, 2001).

The following will consider how swimming may foster social capital within communities.

Tower et al. (2014) used a mixed-methods approach to explore the community benefits of community based aquatic centres in Australia. The research was focused on six individual case studies which encompassed metropolitan and regional sites, with a broad cross-section of demographic characteristics. Of particular interest in the study was the extent to which the aquatic centres created a sense of community connectedness. A questionnaire involving 1373 service users utilised five social capital constructs to elucidate this: Safety, Trust, Acceptance/Reciprocity, Friends and Volunteer/Involved. The authors noted that in general, Safety, Trust and Acceptance/Reciprocity constructs were rated highly by participants, however Friends and Volunteer/Involved constructs were rated low. This suggests that, in these case study sites, the centres were not seen as a space to make friends or be involved as a volunteer. Clearly, this impacts on the ability of the aquatic centres to contribute to the community's social capital. There were however a group of individuals who had higher ratings of all social capital constructs. These were respondents who participated in group activities such as fitness or exercise classes, or swim club/squad training. These activities offered opportunities for participants to make meaningful connections that would generate social capital outcomes (see also Case Study 2). These authors' findings reflect, in part, the positive correlation between membership of/participation in sports groups and the development of social capital described by others. For example Delaney and Keane (2005), utilising existing UK statistical data, concluded that participation in sports groups was associated with higher levels of social trust and trust in institutions, and a greater likelihood of expressing views that immigration was a positive enrichment of cultural life.

Case Study 2

Jean's Story

(Personal communication to author)

Jean, 80, is a full time carer for her elderly husband who is confined to a wheelchair. Jean attends the weekly ladies' swim session at her local community pool – she enjoys meeting the other swimmers who come from very diverse backgrounds, and chats whilst they are in the pool and on poolside. Most weeks, she will stay and have coffee with a number of the other swimmers after the session. She values these informal 'friendships' and claims that it is this stimulating social contact which allows her to cope with the care-giver burden that she increasingly experiences.

Jean recently had to undergo surgery – as a consequence she missed six weeks of swimming. On the second week, the swimmers and pool staff noted Jean's absence and became concerned. Using membership records they traced a telephone number for one of Jean's family and made contact in order to check on Jean's wellbeing.

This case highlights how Jean accesses the social capital of the swimming community as a resource to improve her wellbeing and deal with the challenges of her daily life. The swim group has permitted her to cultivate new friendships and associations across class and ethnic barriers. Furthermore, the social network in which Jean is involved (by virtue of her swim participation) generates a valuable community 'connectedness', thereby extending the framework of support for an elderly community-dwelling lady.

Summary statement: Whilst swimming might be conceptualised as an individual sport, pool-based activities such as swimming clubs and exercise classes have been demonstrated to develop meaningful social networks (for participants and others) that have the potential to generate social capital and thereby bolster community capacity. The research base specific to social capital and swimming/aquatic exercise is however limited. Future empirical work should consider how swimming organisations can best promote social interaction in their facilities and programmes, for example greater use of group activities, unstructured components in training sessions, parallel social activities or the role for social media.

3. Civic Engagement

Intimately related to the idea of social capital is the notion of civic engagement – the manner in which citizens participate in community life in order to ameliorate conditions for others, or to influence the community's future (Adler and Goggin, 2005). Jarvie (2003) suggests that sport is a critical contributor to civil society – occupying a liminal space between the state and the individual – and promoting a communitarian philosophy based upon mutuality and obligations rather than individualism. In many communities, sports clubs have been a key instigator of civic participation whether that be as a club member, a parent, a spectator or a volunteer (Edwards, 2015). It is suggested that there are 30,000 volunteers involved in UK swimming, with an estimated value of £30 million per annum (Burgham and Downward, 2005).

There are in fact, numerous examples of swimming as a catalyst for civic engagement (Amateur Swimming Association/Asset Transfer Unit (ASA/ATU), undated; Griffiths et al., 2014; Jarvie, 2003; Save Victoria Baths! Campaign, Undated). Many of these examples pertain to the desire of local community groups to preserve pools that are viewed as valuable community assets, or "*our pool*" (Griffiths et al., 2014:295). Down (2006, p.96) claims that prevailing neo-liberal logic dictates that "*the market should be the organising principle for all political, social and economic decisions… [involving]… trade and financial liberalisation, deregulation, [and] the selling off of state corporations*". Griffiths et al. (2014) illustrate how this type of neo-liberal discourse is frequently implemented to justify closure of government-funded swimming pools, and how counter-discourses are mobilised from community campaign groups using social justice logic, for example increased travel costs, and reduced accessibility. In many instances, the collective action is focused upon not only preserving the pool, but also instigating local community involvement in its on-going management (Jarvie, 2003). In particular, an increasing number of UK pools are now owned by community enterprises, abetted by the recent publication of a number of significant reports and policy interventions (ASA/ATU, undated). The management of these community enterprise pools is invariably based on Principles of democracy and volunteerism.

Case Study 3
Save Victoria Baths!

(Case content derived from Save Victoria Baths! Campaign (Undated).

Victoria Baths are the oldest swimming pools in Nottingham, providing community facilities to local residents from 1850 as a direct result of the appalling slum conditions. Nottingham's Corporation Surveyor noted in 1852: "The building is of brick and one storey high; the interior is commodious and well-fitted up. There are baths both for males and females, and the charges are exceedingly moderate. They are open on Sundays as well as on week-days, and the wash-houses are open on the week-days from eight o'clock a.m. to eight o'clock p.m. In the latter department there is suitable drying apparatus, and this has been of much benefit among the humbler classes of the community, whose homes do not furnish the requisite convenience for washing. Altogether the admirable situation is calculated to elevate both the physical and moral nature of the inhabitants".

On Friday 8th February 2008, following Nottingham City Council's announcement of their intention to close the 150 year old facility, the 'Save Victoria Baths!' campaign was launched. The campaign team (formed from a collective of local residents, swimmers and heritage groups) orchestrated an overwhelming response including 1300 emails and letters, and numerous petitions. The campaign group were tireless in their efforts creating a 'pop-up-shop' in the market place to canvas local opinion, organising free community fun days, operationalising an active social media presence, and creating art work to publicise their cause.

As a result of the concerted collective action, three members of the campaign group were co-opted to work alongside the city council and other organisations. The campaign ran for a total of 3 years and resulted in the opening of a new £9 million leisure centre built on the site of Victoria Baths, and preserving many of its original features.

The collective action of the campaign group ensured that the plans to move leisure and swimming facilities to a different part of the city in a purpose built 'McLeisure Centre' were stymied. As such, the civic action preserved not only valuable recreational facilities for local residents, but also an important aspect of their community cultural heritage.

Summary statement: Civic engagement is a critical dimension of community capacity because it defines the extent to which community members will engage with issues of public concern, and therefore is indicative of the potential leverage for health and community wellbeing improvement (Wendel et al., 2009). Swimming facilities, as valued community assets, have incited significant civic participation, especially when they have come under the threat of neo-liberal policy. A paradigm shift whereby community collectives become not just the campaigners but subsequently the 'owners' of community pools is apparent. Future empirical work should be attentive to the ability of such social enterprises to influence community capacity.

4. Shared Values

Efforts to develop community capacity should be aligned to a well-defined set of shared community values (Wendel et al., 2009). Edwards (2015) states that, to this end, community sport should be motivated by inclusivity and social justice and cultural enrichment. Skinner et al. (2008, p.22) assert that sport can serve as "*an excellent 'hook' for engaging people who may be suffering from disadvantage and providing a supportive environment to encourage and assist those individuals in their social development, learning and connection through related programmes and services*".

There are a number of studies that indicate how swimming may provide the alleged 'hook' for improving social inclusion within a community. Dagkas et al. (2011) describe how, in Muslim communities, the role of women as wives and mothers is highly honoured, to the potential detriment of their participation in sport, which is considered 'playful', immodest or lacking in worth. Their mixed-methods study involving teachers, young Muslim people and their parents explored the experiences and concerns regarding the inclusion of young Muslim women in physical education. Swimming was particularly problematic for parents, predominantly because of the presence of males in the aquatic environment. In these instances, parental permission was invariably not granted. Where such an impasse arose, successful resolutions were possible when pool managers were able to provide single-sex swimming, and where schools negotiated agreement on mutually acceptable clothing. The authors note that the schools who were most successful in social inclusion engaged the pupils in decision-making with regards appropriate clothing and requirements for participation. Such an approach engendered ownership and empowerment, and greater enthusiasm for swimming and other physical education activities. The authors conclude that social inclusion is best achieved by collaboration between multiple stakeholders, including the local authority, schools, pupils, parents, community members and faith groups.

In their evaluation of the ability of community pools to help develop community connections and promote inclusivity, Tower et al. (2014) revealed a wicked problem. Whilst the mission statements of the aquatic facilities aspired to inclusivity (an aspiration mirrored by the staff interviewed in the study), the financial analysis indicated that minimal resources were allocated to community development programmes. Managers insisted that they intended to pursue goals of social inclusion, but acknowledged the obligation to "*juggle between community and commerce*" (Tower et al., 2014, p.8). Conversely, Bullough et al. (2015) demonstrated that even when community development programmes were fully funded, participation did not necessarily increase. Their evaluation of a free, locally funded swimming initiative targeted at under-19 year olds in a deprived and culturally diverse community concluded that, due to low recruitment of new participants, the cost per swim of the community investment was almost six times more per head than a central government funded scheme. Fifty-one percent of the eligible population applied for a free swim membership, but only 33% of the eligible population activated it. The majority of the cardholders (72%) were already regular swimmers, and they accounted for the greatest proportion of attendances over the programme. The authors note that recruitment could have been adversely affected by the fact that the programme did not teach the requisite swim skills, and therefore may have inadvertently excluded non-swimmers. This is significant as evidence suggests that one in three children in the UK leave primary school unable to swim (ASA, 2012). Bullough et al.'s research highlights that cost is not the only barrier to community swim participation, rather a range of complex factors including facility location, opening hours and programming, public transport, body image and competing demands on free time are likely to be influential.

Aquatic leisure activity is the second most popular physical activity for individuals aged 50 or over in the UK, however participation rates have been in steep decline since 2002 (Evans and Sleap, 2015). In a qualitative study exploring the experiences of leisure time physical activity in 14 individuals aged 55 and over, Evans and Sleap (2015) concluded that the socio-historical embodied experiences of swimming significantly defined individuals' current perceptions. They suggest that to improve participation amongst older adults, (mis)conceptions regarding safety, hygiene and poor facilities should be addressed. The benefits to the community of engaging older adults swimming and other aquatic activity have been alluded to by Pike (2012). Using interview data from swimmers aged 60 years and over, Pike suggests that swim participation has the potential to challenge the construct that older people are dependent and burdensome to societal resources, and instead facilitate a more socially acceptable identity that redresses the stigmatisation of ageing.

Individuals with physical or intellectual disability often do not have the same opportunities to participate in sporting activities alongside nondisabled peers (Oriel et al., 2012). In children in particular, this can lead to social isolation and rejection, with implications for social, emotional and intellectual development (Siperstein et al., 2009). Oriel et al. (2012) investigated the psychosocial effects of an inclusive, eight week, community-based aquatic exercise programme for 23 children with and without disability. At pre-test, the children with disabilities were less accepted by their nondisabled peers, as indicated by a higher number of negative nominations using the Peer Sociometric Nomination Assessment. At post-test however, children with disabilities were more accepted by both groups of peers, indicating improved social acceptance.

Summary statement: Research suggests that swimming has the potential to promote opportunities for social inclusion and cultural enrichment within community settings, however economic and socio-cultural factors are likely to influence the relative effectiveness and efficiency of swim participation programmes. Organisations should be cognisant of this complex array of influences in the design of such programmes. Co-production of social inclusion programmes may be a promising method for improving swim participation.

Conclusion

This chapter has sought to demonstrate the efficacy of swimming in contributing to community capacity. Utilising a theoretical framework predicated on the constructs of human capital, social capital, civic engagement and shared values, and supported with data from empirical research, it is evident that there is the potential for a positive association between swimming/aquatic leisure participation and community wellbeing. What remains unclear however, are the specific processes that produce social change, and the contexts in which these might occur.

It is worthy of note that there is a relative dearth of evidence in this particular field. Consequently this chapter has made a number of recommendations for future research exploring swimming and communitarianism. Future studies should endeavour to utilise systematic and robust evaluation of programmes, and consider the capture of longitudinal evidence.

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Chapter 5

The public health benefits of swimming: a systematic review

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Key words:

swimming
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Introduction

What is Public Health and why is it important?

There is now widespread recognition that our health and wellbeing is determined by more than simply our genetic makeup or access to healthcare (Marmot 2015, Marmot 2016, Marmot and Bell 2016). Importantly, lifestyle behaviours (for example physical activity and nutrition) in addition to the social determinants of health, including our physical, social and economic circumstances in the location we are born and live, have a considerable impact on both the length and quality of our lives (Marmot 2015, Marmot 2015, Stringhini, Carmeli et al. 2017). Gross inequalities exist in society, which are largely attributed to variations in social determinants and lifestyle behaviours, accounting for a considerable portion of the disturbing variation in life expectancy of approximately 48 years between twenty countries (Marmot 2005, Marmot and Allen 2014, Marmot 2015). Addressing such inequality is the heartbeat of public health interventions. The World Health Organisation (WHO) influential Acheson report defined public health as *"the art and science of preventing disease, prolonging life and promoting health through the organized efforts of society"* (Acheson 1988).

The importance of Physical Activity for Public Health

There is now irrefutable evidence that leisure activities, physical activity, sport and exercise are good for the health and wellbeing of individuals across the lifespan and consequently promoting physical activity is a key public health priority (Nelson, Rejeski et al. 2007, Biddle and Asare 2011, Biddle, Brehm et al. 2012, Naci and Ioannidis 2013).

Specifically, in children and adolescents, higher levels of physical activity, particularly moderate to vigorous physical activity (MVPA), are associated with better physical (for example improved cardiometabolic markers, lower obesity levels), cognitive (for example neuropsychological performance, academic performance), emotional and mental health benefits (for example lower risk of developing depression, increased resilience) (Jackson, Davis et al. 2016, Lubans, Richards et al. 2016, Stoner, Rowlands et al. 2016, Korczak, Madigan et al. 2017). Similar public health and wellbeing benefits of physical activity and exercise have been reported in adults of working age (Biddle, Brehm et al. 2012, Reiner, Niermann et al. 2013, Oja, Titze et al. 2015, Schuch, Vancampfort et al. 2016, Schuch, Vancampfort et al. 2016). Moreover, physical activity and exercise can improve a plethora of health outcomes in older age (Nelson, Rejeski et al. 2007, Sun, Norman et al. 2013) and may play an important role in addressing age specific public health priorities such as preventing falls (Stubbs, Brefka et al. 2015).

In addition to the aforementioned benefits, physical inactivity is estimated to be a leading modifiable risk factor associated with premature mortality ((WHO) 2014) and potentially associated with a similar number of premature deaths as smoking (Public Health England 2014). There is evidence of a dose response relationship between physical activity and mortality, with higher levels of total, leisure, activities of daily living, occupational activity and all intensities of physical activity/exercise being associated with a reduced risk of premature mortality compared to the lowest activity levels (Samitz, Egger et al. 2011). A similar relationship is evident in older adults (Hupin, Roche et al. 2015), with the authors of a recent meta-analysis suggesting that swimming could play a key role in helping older adults reduce mortality (although they found no direct data investigating the relationship between swimming and mortality in older adults). However, there is promising evidence that replacing sedentary behaviour with moderate physical activity (of about 60-75 minutes per day) can eliminate the risk of death from high amount of sitting time (Ekelund, Steene-Johannessen et al. 2016).

Public health initiatives and potential for swimming to play a central role

Given the plethora of evidence for physical activity and sport on health and wellbeing, numerous International ((WHO) 2014) and national initiatives have been developed (Public Health England 2014) stressing the important of promoting physical activity. Many of these guidelines make specific recommendations regarding the amount and intensity of physical activity that different populations should seek to achieve. For instance, in their initiative *"Everybody Active Everyday"*, Public Health England recommends that adults participate in 150 minutes of physical activity respectively per week (Public Health England 2014). Swimming may be uniquely placed and have a pivotal role to help everybody to be active every day from the cradle to the grave. Specifically, swimming is an activity that people can participate in regardless of age, ethnicity, gender and culture and may offer a unique strategy for people to engage in a meaningful activity (Thomson, Kearns et al. 2003, Oh and Lee 2015). In addition, a recent large study among 80,306 British adults, the authors found that any amount of swimming participation compared to those who engaged in none, was associated with a 28% and 41% reduction in all cause and cardiovascular disease cause mortality respectively (Oja, Kelly et al. 2016). Thus, there is promising evidence that swimming may help reduce premature deaths due to inactivity. Another core public health concern is the prevention and management of obesity (Aune, Sen et al. 2016). Given that physical activity is central to addressing the obesity epidemic (George, Kristi et al. 2016, Garcia-Hermoso, Ceballos-Ceballos et al. 2017) and swimming is a robust form of energy expenditure (Trappe, Gastaldelli et al. 1997), the potential for swimming to address this public health priority is considerable.

Swimming participation

Swimming may also be uniquely placed to provide public health benefits given the fact it remains a popular form of physical activity. A recent meta-analysis of worldwide global sport and leisure activities (Hulteen, Smith et al. 2017) demonstrated that swimming was consistently rated in the top five leisure participated physical activities in children and adolescents across Africa, Eastern Mediterranean, Western Pacific, Americas and Europe. However, in adulthood, the same meta-analysis found that swimming was only in the top five commonly participated physical activities in the Eastern Mediterranean and Western Pacific. Swimming remains very popular in England, with national data in England from the Active People Survey by Sport England (Sport England 2016) demonstrating that between October 2015 and September 2016, 2,516,700 people aged 16 years or older reported swimming (including all swimming and diving (indoor and outdoor), water polo, deep water swimming, open water swimming, deep water diving) at least once a week. However, the same report found that numbers engaging in swimming are just over 750,000 fewer than ten years earlier, which is clearly a concern. Taken together, it appears that swimming is universally popular in adolescence and childhood, but that participation numbers are declining, with the transition from childhood to adulthood a critical window. The precise reasons for this relationship are unclear and warrant investigation as a matter of priority to inform interventions to prevent this potential missed opportunity.

Swimming may also play a key role in addressing another important public health concern, drowning, which remains the leading cause of death in the United States in children and adolescents and disproportionately affects those who are non-Caucasian (Weiss 2010). The numbers of people drowning in the United Kingdom (UK) has declined over the last 20 years with 381 deaths in 2013 (The Royal Society for the Prevention of Accidents 2016). Swimming ability may reflect drowning disparities (Stempski, Liu et al. 2015). Thus, having adequate opportunities to learn to swim and have positive experiences in early life, particularly among those from disadvantaged backgrounds, may be an important to tackle this leading cause of avoidable and tragic death.

Given the potential for swimming to play a key role to help people from the cradle to the grave meet physical activity targets, tackle obesity and experience public health benefits, there is a need to synthesis the literature on the potential public health benefits across the lifespan. The current chapter comprises a synthesis of results following a comprehensive literature search over four electronic databases and screening of 1662 articles in addition to citation chasing across the Google Scholar database and reference checking of the identified articles. The specific questions of this systematic review chapter are:

1. What are the public health benefits of swimming for the individual and communities across the lifespan from cradle to the end of life?
2. What are the public health risks (for example asthma, reduced bone mineral density) and are these based on evidence?
3. What are the risks of drowning and how can leaning to swim negate this risk?

The final summary section of the chapter summarises the gaps within the literature and makes recommendations for future research initiatives.

Public health considerations of swimming in children and adolescents

There is irrefutable evidence that physical activity is good for children's health (Biddle and Asare 2011, Lubans, Richards et al. 2016). As illustrated above, childhood is a time when swimming is universally popular and participation levels seem to drop once adulthood is reached (Hulteen, Smith et al. 2017). Whilst there is no clear evidence illustrating why this observation occurs, it is known that water trauma or negative swimming experiences in earlier childhood may have a negative impact on later participation and lead to a fear of water and swimming in adulthood (Poulton, Menzies et al. 1999). This suggests the need to ensure that earlier childhood experiences of swimming are accessible and that opportunities are available for people who may have had negative experiences can enter the water before they enter adulthood.

There is a paucity of evidence investigating the direct public health benefits of swimming among children and adolescents. One small intervention study investigated the potential benefits of swimming three times a week for 60 minutes at 50-75% maximal heart rate over 12 weeks among 10 obese primary school age children versus a control condition (n=10) (Lee and Oh 2014). The study found some provisional evidence that weight, body fat percentage and fat free mass significantly decreased from baseline to follow up among the swimming group. However, the small sample size, and lack of randomisation precludes any firm conclusions to be drawn from this study on the potential benefits of swimming on obese young children. Another study (Ganciu 2015), suggested that swimming three times a week (aiming for a total of 100 minutes per week) over a 6 month period with a combined regimented dietary program resulted in weight loss, reduced waist circumference and obesity risk among 25 University students compared to a control condition. However, the study is of remarkable poor quality and no firm conclusions can be made based on this study. Apart from these studies, there is a virtual absence of studies specifically investigating swimming and tackling the obesity epidemic in young people. **Future research is urgently required to consider how swimming can play a role in addressing the obesity epidemic in children and young people.**

There have been some concerns expressed about the potential deleterious consequences of swimming pool attendance and participation in childhood, including concerns regarding bone health and respiratory conditions (Gomez-Bruton, Gonzalez-Aguero et al. 2013, Dick, Friend et al. 2014). These concerns are not founded on convincing science at this moment in time. A recent large meta-analysis of 14 studies compared bone mineral density levels at various skeletal sites (including the lumbar spine, femoral neck and whole body) and found that children and adolescents who engaged in regular swimming had comparable levels of bone mineral density compared to sedentary controls (Gomez-Bruton, Montero-Marin et al. 2016). However, the authors found that compared to children who engaged in other forms of osteogenic sports (for instance weight bearing land based exercises), children that swam had reduced lumbar spine (Hedge's G=0.65, $p<0.001$), femoral neck (Hedges G = -1.09, $p<0.001$) but no difference was observed in whole body bone mineral density. The authors suggest that (Gomez-Bruton, Montero-Marin et al. 2016) children who frequently swim, may wish to complement their training with additional weight bearing exercises to improve their bone mineral density at the femoral neck and lumbar spine.

Of equal concern is that swimming pool attendance has been associated with asthma and adverse respiratory consequences, with several studies suggesting a link, whilst others have found no evidence of a relationship. Given this, a recent meta-analysis (Valeriani, Protano et al. 2016) including seven studies and 5851 children found that swimming pool attendance was not associated with an increased odds of having asthma compared to controls (OR, 1.084; 95% CI: 0.89-1.31). Perhaps the most robust evidence derives from a prospective cohort study in England, which followed 5,738 children over 81 months (Font-Ribera, Villanueva et al. 2011). The authors found that swimming was actually associated with lower levels of asthma and other lung conditions. In addition they found that among children aged 4-7 who engaged in higher levels of swimming versus children of similar age who neve swam, had improvements in lung function, specifically better forced vital capacity and forced expiratory volumes were noted. Moreover, a study among 2,205 babies found that attending swimming pool in their first year was not associated with an increased odds of lower respiratory tract infection, wheezing, persistent cough, eczema or otitis (Font-Ribera, Villanueva et al. 2013). Thus, there does not appear to be adequate evidence to suggest that swimming is associated with asthma or respiratory conditions in childhood in children and is actually associated with better lung function.

In addition to the aforementioned, providing swimming may be a cost effective method of physical activity. A recent study considering physical activity among young people in the community levels before and after a number of physical activity interventions, ranked swimming as 3rd at a cost of £200 per quality adjusted life year (QALY) with a National Health Service (NHS) saving of £2,111 per completer (Pringle, Cooke et al. 2010). Little evidence of the QALY of swimming is available beyond this study and such research should be a priority in the future. Moreover, future research is required to consider the potential impact of swimming on general physical activity levels, since data on this is sparse.

Free swimming initiatives: an important public health opportunity to address social disadvantages

There is an increasing body of evidence that poor socioeconomic status and deprivation is associated with worse health outcomes such as higher levels of obesity, diabetes and ultimately earlier death (Goldblatt 2016, Marmot and Bell 2016, Stringhini, Carmeli et al. 2017). Yet, there is optimism that such social disadvantages are amenable to change (Marmot and Bell 2016). Consequently, there is considerable potential for physical activity and swimming to play a role in addressing such inequalities (Grzywacz and Marks 2001). Social patterns are evident among swimming participation, with children from lower socioeconomic class less likely than those from higher socioeconomic class to engage in swimming (Audrey, Wheeler et al. 2012). However, this is the socioeconomic class with the widest disparity in terms of health, wellbeing and outcomes and thus addressing this gap is a priority in terms of health outcomes (Audrey, Wheeler et al. 2012, Marmot and Bell 2016). In 2009 as part of a broader plan to secure a legacy after the London 2012 Olympic Games, a two year initiative began in England in which participating local authorities gave free swimming lessons to children <16 years and adults >60 years (Audrey, Wheeler et al. 2012). One study (Audrey, Wheeler et al. 2012) evaluated the available data in Bristol among children (<16 years of age), and contrary to their hypothesis, they found that children from most deprived areas were just as likely to take up the free swimming as those in the most affluent areas. However, the authors found that having a swimming pool close by in the deprived areas was important, since lower rates of swimming were noted in the most deprived when the pool was further away and during the winter ($p<0.001$). Of interest, the authors noted that young girls were more likely to take up the free swimming compared to boys ($p=0.004$), which may be important given the reported low levels of physical activity among young girls (van Sluijs, McMinn et al. 2007, Nooijen, Galanti et al. 2017). Unfortunately, the free swimming initiative was stopped by the government in 2010 due to budgetary constraints (British Broadcasting Company, 2010), and it may have removed an opportunity to promote physical activity equally across the social gradient (Audrey, Wheeler et al. 2012).

A recent study in a large city in England investigated the impact of the local authority providing free swimming passes to 1,011 young disadvantaged children in order to evaluate if this scheme could improve physical activity levels and wellbeing (Pringle, Zwolinsky et al. 2014). Referrals were made by healthcare practitioners (for example General Practitioners, nurses), teachers and community workers or self-referrals. The initiative specifically targeted children who may be disadvantaged, in terms of geographical location, economic circumstances, education, family background, health profile, black and ethnic minority groups or any other reason deemed reasonable. The free swimming passes included unrestricted access to public swimming sessions in the evenings, weekends, school holidays in addition to more structured swimming activities led by the local authority program coordinators and support staff including diving, lifesaving, water polo, inflatable fun sessions and water based youth clubs. The initiative demonstrated that much greater improvements in self-report physical activity were seen in young girls than boys. However, 77% and 87% of females and males respectively, who were sedentary at baseline increased their physical activity and half of participants not meeting recommended PA guidelines increased their physical activity after the intervention. However, the authors noted that males were much more likely than females to be sufficiently active at baseline. Thus, importantly, the authors of this study (Pringle, Zwolinsky et al. 2014) conclude, like another study (Audrey, Wheeler et al. 2012), that providing free swimming appears to be particularly effective among young girls, who typically have lower levels of physical activity and may benefit most. This has significant implications for Swim England implementation strategies in addressing the inactivity epidemic predominantly in young girls.

In another examination of the free swimming program (FSP) in the South of England (Kokolakakis, Pappous et al. 2015), evidence was found of an increase in the access of swimming among children (11-16 years). However, this did not translate to an actual increase in participation of achieving more than 30 minutes of swimming per week.

Of interest, the authors found results suggesting that providing free swimming pool access increased swimming participation (defined as swimming for 30 minutes or more per week) among those with lower education (odds ratio 1.9, p=0.05). An observational study in two deprived neighbourhoods in Glasgow interviewed 81 people who used the swimming pools (Thomson, Kearns et al. 2003). The participants all reported that the swimming was important to their health and wellbeing and emphasised that it was an important means of increasing their physical activity and improving social contact with others in the community (Thomson, Kearns et al. 2003).

Thus taken together, there is some tentative evidence that providing free swimming appears to increase swimming uptake, particularly among young girls and those across the social class spectrum. Such initiatives may be an important strategy to increase participation among hard to reach groups. However, the evaluation of such initiatives is methodologically poor and it appears there has been a missed opportunity to collect public health information at the time of such initiatives. Going forwards, it is important that more robust research methods are used to capture changes in physical activity and other important public health constructs, such as maintenance of a healthy weight, obesity, wellbeing and mental health.

General adults

A recent systematic review (Oja, Titze et al. 2015) considered the health benefits of a range of sport disciplines and the authors identified nine studies considering swimming in adults. The authors (Oja, Titze et al. 2015) reported across three prospective cohort studies, swimming was not associated with weight change or altered risk in cardiovascular disease, however one study noted a significant reduction in all-cause mortality (Chase, Sui et al. 2008). Specifically, (Chase, Sui et al. 2008) investigated 40,547 men age 20-90 years who completed a health examination during 1971 – 2003 and analysed the influence of swimming on mortality versus walking and running. The authors found that after adjustment for age, body-mass index, smoking status, alcohol intake, and family history of cardiovascular disease, swimmers had a 53%, 50%, and 49% lower all-cause mortality risks than men who were sedentary, walkers, or runners, respectively ($p<0.05$ for each). The results suggest that swimmers had a lower risk of early death versus men who were sedentary, engaged in walking or running only. In one randomised control trial (Carrasco, M et al. 2012), a significant but small decrease in body mass index among swimmers versus the control group was noted among post-menopausal women. Beyond this systematic review and the articles contained within, there is a paucity of evidence investigating the public health benefits of swimming in the general adult population. There is also a notable dearth of research considering the influence of swimming on physical activity levels in adults. Although, a systematic review considering the impact of fatherhood on physical activity and sports participation, suggested that swimming among older men, is a popular means to acquire health benefits since it does not contain a game element (Pot and Keizer 2016).

Moving forwards, it is essential the research is conducted to investigate the influence of swimming on public health outcomes in the general adult population.

Pregnancy

There have been some concerns that some of the disinfectants used to sterilise swimming pools may be harmful to expectant mothers, fetal growth and birth outcomes (Juhl, Kogevinas et al. 2010). A Danish birth cohort study investigated the self-report swimming behaviour, prospectively with 78,486 women followed up through and after pregnancy. The authors found that compared to women who did not swim, women who swam in early/mid-term had a slightly reduced risk of giving birth pre-term (hazard ratio (HR) 0.80, 95% CI 0.72-0.88) or giving a birth to a child with congenital malformations (HR 0.89, 95% CI 0.80-0.98). Thus, the authors suggest that swimming does appear to be safe for pregnant mothers to the end point they considered.

There is a paucity of scientific research considering the public health benefits of swimming during pregnancy.

Older adults

Engaging in physical activity in older age is essential for healthy ageing (Windle, Hughes et al. 2010). Specifically, higher level of physical activity promote cognitive health (Hamer, de Oliveira et al. 2014, Hamer, Lavoie et al. 2014, Stubbs, Chen et al. 2017), mental health (Schuch, Vancampfort et al. 2016), physical function and reduce falls risk (Stubbs, Brefka et al. 2015). Thus, the potential for swimming to have a central role in addressing public health in older age is considerable.

Data directly investigating the public health benefits of swimming in older age is sparse. However, a study found that regular older swimmers (n=16) who swam between two and five times a week over a period on average of 2.5 years, had significantly better executive function on three tasks, compared to sedentary older adults of similar age and gender (Abou-Dest, Albinet et al. 2012). Interestingly, the authors observed that the better improvements in executive function among swimmers was not attributed to cardiorespiratory fitness. However, the small sample size and lack of intervention study design preclude any form conclusions being drawn from this study.

One of the biggest public health concerns in older age is falls, which are a leading cause of disability, mortality and admission to long term care facilities (Lamb, Jørstad-Stein et al. 2005, Gates, Smith et al. 2008, Gillespie, Robertson et al. 2012). In the general population, a previous umbrella review of all the top tier of evidence (for instance systematic reviews of meta-analyses of randomised control trials) demonstrated that exercise was the most consistent beneficial intervention on preventing falls in older age (Stubbs, Brefka et al. 2015). Little information is available on the influence of swimming on falls. However, one study (Merom, Stanaway et al. 2014) considered the relationship between swimming, golf, calisthenics, lawn bowls and aerobic exercise machines on future falls among 1,667 older people followed up on average over 43.1 months. The authors found that only swimming significantly reduced the risk of future falls (incidence rate ratio 0.69, 95% CI 0.45-1.0, fully adjusted model) whilst none of the other sports influenced the rate of falls. The possible reasons for the reduced falls in the swimmers, might be explained by the significantly lower (better) postural sway, which is a strong predictor of future falls (Deandrea, Lucenteforte et al. 2010). The potential benefits of water activities on falls risk was illustrated in another intervention study (Arnold and Faulkner 2010). The authors evaluated seventy-nine adults (65 years and older) with hip osteoarthritis and randomised them to one of three groups 1) water aquatics and education (aquatic exercise twice a week with once-a-week group education), aquatics only (twice a week aquatic exercise) and control (usual activity). The authors found that aquatic exercise significantly reduced fear of falling and improved functional performance compared to control conditions.

Taken together, there is promising evidence that in older people, swimming could play an important role in preventing falls. However, going forwards, appropriately designed research is required to consider in a robust way if swimming and aquatic exercise can help improve balance and falls in the older population.

Vulnerable populations

In certain populations who may have low levels of physical activity, swimming may be a particularly valuable means to help people achieve PA and acquire the associated public health benefits. For example, in a recent study among young adults with cerebral palsy (n=54), swimming was the third most popular form of activity, with 53.7% reporting that they swam on at least one occasion in the previous three months (Usuba, Oddson et al. 2015). In addition, a recent systematic review found that swimming has several benefits on motor skills among children with cerebral palsy (Roostaei, Baharlouei et al. 2016). Another intervention study found that swimming resulted in an actual increase in self-reported physical activity among those with cerebral palsy (Lai, Liu et al. 2015).

Addressing public health priorities

One example of swimming being utilised to address two public health priorities, namely obesity and drowning, is the “Everyone swims” program in Washington, the United States (Stempski, Liu et al. 2015). The program was a partnership between 21 community health clinics, 28 swimming pools, 9 beaches and 2 rowing houses which was designed to promote policy and systems change to make swimming safe and create access for low income and diverse families. Whilst the authors did not record access to swimming pool, changes in swimming behaviours or any public health measures, the authors found through stakeholder interviews that higher numbers of swimmers were noted by using standardised screening for swim ability, referring patients from clinics to water organisations, using improved scholarship form and processes and developing special swim programs. The authors propose a socioecological model of factors based on (Sallis, Cervero et al. 2006) model which influence swimming and water recreation including:

Individual factors- ability to swim, personal cultural beliefs about swimming/water, comfort with water, familiarity with pools.

Family factors - ability to swim, beliefs about swimming, comfort with water, familiarity with swimming pools.

Community/ institution factors – Water program information readily available (including non-English), pool scholarships, scholarships for low income families/children, availability of single sex sessions, health clinics and pools working together.

Policy factors – Pools allowing diverse swim wear, single sex swimming time allocations.

Whilst of interest, no formal evaluation of this model, or the program to tackle obesity and drowning is available. **Future UK based research might wish to consider combining robust evaluations of swimming to tackle public health priorities such as obesity, increasing physical activity, wellbeing and reducing the risk of drowning.**

Drowning and swimming

Drowning kills approximately 4,000 people in the United States and more than 300,000 people across the world each year (Mott and Latimer 2016). In Europe, drowning accounts for approximately 6500 deaths (or 5%) of unintentional deaths per year (Moufatti and Petridou 2014). The latest figures from the Royal Society for the Prevention of Accidents suggest that 381 people died from drowning in the UK in 2013 (The Royal Society for the Prevention of Accidents, 2016).

Worldwide, it is estimated that 1.3 million disability-adjusted life years (DALYs) were lost due to death or disability due to drowning in 2004 (Martyn 2014). Whilst in some high income countries such as the United States, there had been a decline in drowning deaths, large numbers (5,800) are treated in emergency departments and/ or require hospitilisation (Bowman, Aitken et al. 2012). In addition, long term adverse neurological disabilities such as quadriplegia or persistent vegetative state occur between 5-10% of drowning victims (Weiss 2010). There are marked discrepancies between drowning rates in high income countries compared to Low and Middle income countries in drowning rates, with higher rates noted in the latter. Drowning is associated with inequality, with a recent study in the United States demonstrating those from poor backgrounds disproportionately affected (Quan, Pilkey et al. 2011). Another large study in the United States investigating 19,403 emergency department attendances over 5 years due to drowning, found that children from racial/ ethnic minorities were more likely to experience non-fatal drowning (Felton, Myers et al. 2015). Disparities among fatal drowning appear greatest in swimming pool settings, with a recent study analysing death certificate data over 12 years in the United States finding that black Americans were 5.5 times more likely to die from drowning than whites in these settings (Gilchrist and Parker 2014). Little research has been conducted in the UK on drowning and none is available on the potential social gradient and drowning risk. One old study among children under 15 years investigated 306 drowning incidents (Kemp and Sibert 1992) and found that 149 died and 157 survived after near drowning. The authors reported the death from drowning was lowest in public pools 6% and highest in rivers, canals, and lakes (78%) with most of the children (263, 83%) being unsupervised at the time of the incident.

There is a diverse range of definitions of drowning, with a previous systematic review identifying 33 differing definitions (Papa, Hoelle et al. 2005). Consequently, the World Health Organisation agreed on the following definition *"Drowning is the process of experiencing respiratory impairment from submersion/immersion in liquid"* (van Beeck, Branche et al. 2005). Drowning is rarely caused by a single factor and prevention efforts should therefore be reflective of the multifactorial nature of drowning (Mott and Latimer 2016). Drowning in children is not always associated with a lack of adult supervision, but often a lapse in concentration of the supervising adults (Weiss 2010). Alcohol consumption can impair judgement, performance in addition to having adverse physiological effects for example lack of orientation, altering perception to temperature (Thompson, Oram et al. 2016)) (Weiss 2010). Swimming ability is another key risk factor for drowning which can potentially be amenable and improved with appropriate swimming training interventions. Despite a suggested link, the relatively recent American Academy of Paediatrics review on the topic stated that *"there is no clear evidence that drowning rates are higher in poor swimmers"* (page 256) (Weiss 2010). However, there are a few retrospective studies that have suggested that swimming lessons may be associated with a reduced risk of drowning in small children. A study in China demonstrated that children who drowned were less likely to have had swimming lessons (6.8%) than children that did not drown (12%) (Yang, Nong et al. 2007). Another small study investigating 61 drowning deaths in children aged 1-4 years of age and 27 5- 18 year olds found that formal swimming lessons were associated with approximately a 88% decreased odds of drowning (odds ratio 0.12, 95% 0.01-0.97) (Brenner, Taneja et al. 2009). However, swimming lessons or swimming ability does not ensure that a person is not at risk of drowning (Weiss 2010). For instance, a study of children aged less than five found that 17% of those that drowned had received swimming lessons previously (Hassall 1989).

There is no consistent evidence of the best method to prevent drowning to date (Weiss 2010). Some interventions that have worked include pool fencing with an odds ratio of 0.27 (95% CI 0.16-0.47) indicating that pooling fencing is associated with a 73% decreased odds of drowning compared to no fencing (Thompson and Rivara 2000). In a review and grading of the available evidence key recommendations for preventing drowning in practice revolved around three area (Mott and Latimer 2016), although the authors stressed there is a lack of high quality evidence. First, alcohol greatly increases drowning risk and should not be given when participating in water activities (Consensus, evidence based expert opinion). Second, in drowning victims, the order of resuscitation efforts should be airway, breathing and compressions (ABC) (Consensus, evidence based expert opinion). Third, educational programs about the dangers of drowning, swimming and water safety lessons and pool fencing may be effective in preventing childhood drowning (evidence rated as inconsistent or limited quality orientated evidence) (Mott and Latimer 2016).

Specifically, with adequate swimming supervision, swimming instruction and public education measures, it is estimated that approximately 85% of drownings may be preventable (Mott and Latimer 2016). At the time of writing, the American Academy of Paediatrics report state there was no scientific study investigating if lifeguard presence is associated with a reduction in drowning incidents (Weiss 2010). However, there is some evidence from South Africa that substandard lifeguard performance (for example being inattentive) delayed the resuscitation and retrieval process of drowning victims (Modell 2010).

Most recently, a systematic review found seven articles (two randomised control trials, one trial without a control group, three case control studies and one evaluation) and explored the evidence of drowning prevention efforts in children and adolescents (Wallis, Watt et al. 2015). Three of the included studies investigated the potential benefits of education and only one considered an objective measure on drowning fatalities (Bennett, Cummings et al. 1999), although the numbers were too small to establish any difference. The authors (Wallis, Watt et al. 2015) identified two studies investigating water and swimming safety lessons however noted there were considerable limitations in the quality of the studies, thus precluding any definitive conclusions. One study suggested that swimming skills improved swimming ability in children aged 2-3 but no data on drowning was provided and there was no control group (Asher, Rivara et al. 1995). In the second study as described above the authors found retrospective evidence suggesting a protective effect of swimming lessons on drowning (Brenner, Taneja et al. 2009). Finally, this systematic review found two studies (one American and one Australian) providing mixed evidence on the benefits of pool fencing.

Clearly, more robust research is required before any firm conclusions can be made about addressing the public health priority of reducing the incidence of drowning.

Summary and recommendations

Despite the popularity of swimming, there is a notable paucity of evidence investigating the public health benefits.

Overall, the evidence base for the public health benefits of swimming is very limited and the evidence that is available is of remarkably poor quality, precluding any firm conclusions being made.

Specifically, in key public health priorities such as addressing the obesity epidemic, increasing physical activity or preventing drowning, there is limited evidence of the benefits of swimming. However, there is insufficient evidence to suggest that swimming in childhood is associated with worse respiratory health (for example asthma) or poor bone health (in later life). There is some tentative evidence that providing free swimming pool access may increase swimming participation, particularly among those from disadvantaged backgrounds. There is also some tentative evidence that swimming may potentially reduce the risk of earlier death compared to people who are more sedentary or men who engage in walking or running.

Recommendations

- Investment is required for research to consider how swimming initiatives, such as free swimming, can help increase physical activity participation and help address social determinants of health. Such initiatives should specifically consider and target key groups, such as increasing physical activity among young females and swimming participation among those from lower socioeconomic status or black and ethnic minority groups.
- Future research is urgently required to consider how swimming can play a role in public health priorities, such as addressing the obesity epidemic in youth and across the lifespan.
- Future research is required to more broadly capture the public health benefits of swimming – including key areas such as increasing physical activity, wellbeing, mental health and reducing the risk of drowning.
- Future research in older age may wish to consider how swimming and aquatic exercise may help improve balance and reduce falls risk.

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Appendix

Methods

The current systematic review was conducted in accordance with best practice, namely the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Statement (PRISMA)1. A pre-specified but unpublished protocol was adhered to as set out below.

Eligibility Criteria

Studies were considered eligible if they met the following criteria:

Population – People of any age, gender and ethnicity were eligible.

Intervention – Studies considering any type of swimming or aquatic activity (structured or unstructured) in a swimming pool or natural waters (e.g. lake, sea) were considered. This review also included non-quantitative (e.g. qualitative) studies considering people's experience of swimming and wellbeing. Policy studies considering swimming were also considered eligible.

Comparator – Studies investigating the public health benefits or considerations of swimming with and without any comparison group are eligible.

Outcomes – Any quantitative or qualitative study reporting any public health outcome were included including physical activity, obesity, and addition to the social determinants of health. In addition, studies reporting public health considerations associated with swimming such as drowning were included. Policy papers considering public health outcomes were also included.

Study Design – A wide range of study designs were eligible including intervention studies (Randomised controlled trials (RCT), nonrandomised controlled trials, pre and post-test intervention studies), observational studies (including case control, cohort or survey data) and qualitative studies (including focus groups, individual interviews). In addition, previous systematic reviews, syntheses or policy papers were also eligible.

Search Strategy

In order to inform this systematic review, the following search procedures were undertaken. First, an electronic database search of Embase (1974 to 2017 Week 07), PsycINFO (1806 to February Week 2 2017), Social Policy and Practice (inception to 18.2.2017) and Ovid MEDLINE (Inception to 18.2017) was undertaken. The electronic database search was undertaken using the following key word search terms (swim* or swimming pool or aquatic therapy) and (public health or benefits or social determinants or inequality). Second, the database Google Scholar was searched on 18.2.2017 using various combinations of key search terms to identify specific articles potentially meeting the inclusion criteria. Third, combinations of key search terms were used in the main Google search database to identify nonacademic literature of potential relevance (e.g. policies). Finally, the reference lists of included articles was undertaken to identify articles that meet the inclusion criteria.

Study Selection

All 'hits' from the searches were exported into an excel file. One author (BS) reviewed the abstracts and titles of all hits and then developed a list of potentially eligible articles that were considered at the full text review. At the full text review, the eligibility criteria were applied and a final list of included studies was considered to inform the review.

Data extraction

Data or qualitative quotations were extracted on a predetermined database.

Synthesis of results

Due to the anticipated heterogeneity in terms of study deign, populations and outcomes, a quantitative synthesis (e.g. meta-analysis) was not deemed appropriate. Therefore, a best evidence synthesis was undertaken to address the questions of the review.

Search results

The initial database search resulted in 2,395 potentially eligible articles being identified, which was subsequently reduced to 1,662 after deduplication.

Chapter 6

Swimming as a sport – the health and wellbeing benefits: a systematic review

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Introduction

This chapter is about the health and wellbeing benefits of swimming as a sport. It is important to distinguish between physical activity and sport. Eleven per cent of adults in England reported taking part in the physical activity of swimming in 2015-2016 (Sport England, 2016a). The number of people taking part in swimming competitions increased by over five per cent in 2015-2016 to almost 70,000 (Amateur Swimming Association, 2016). In the section, Methods, we define physical activity, exercise and sport. We explain that sport is a form of physical activity that involves competition. Subsequently, we describe the systematic review we conducted. We explain that best practice was followed in conducting the review. We then explain how evidence statements were produced with regard to the type and strength of evidence. In this section, Results, we summarise the evidence that was found and we provide evidence statements. We state that there is no experimental evidence of the health and wellbeing benefits of swimming as a sport. We also state that there is moderately strong observational evidence that chronic disease risk factors, like blood pressure, are better in masters swimmers than the general population. Low physical fitness is one of the strongest predictors of mortality and we state that there is moderately strong evidence that physical fitness is high in masters swimmers. In the section, Discussion, we offer our interpretation of the evidence. Then, we discuss what the sport of swimming might learn from the sport of football; and we discuss the role of technology. We explain that high training loads may increase the risks of injury and illness in swimmers and other competitive athletes. Next, we discuss the limited impact of London 2012 on swimming participation. Finally, we offer recommendations for future research and policy making.

Methods

Defining physical activity, exercise and sport

In the broadest sense, any volitional movement of skeletal muscle that results in energy expenditure is regarded as physical activity (Caspersen, Powell, & Christenson, 1985). Exercise is a form of leisure-time physical activity that is planned, structured, and repetitive. Exercise training is purposeful and is performed with specific external goals, including the improvement or maintenance of physical fitness, physical performance or health (Bouchard & Shephard, 1994; Caspersen et al., 1985). Sport is a form of physical activity that includes rules and is usually competitive. The true sense of sport is broad: "Sport means all forms of physical activity, which, through casual or organised participation, aim at expressing or improving physical fitness and mental wellbeing, forming social relationships or obtaining results in competition at all levels" (Council of Europe, 1993). The UK government recognises that sport is part of our national identity and that the power of sport should be harnessed for the good of our whole society (HM Government, 2015). Swimming is a relatively popular physical activity (Sport England, 2016a); however, it is unclear whether or not competition is important to swimmers (Sport England, 2012b).

Defining health and disease

Health has been defined as, "A state of physical, mental, and psychological wellbeing, and not merely the absence of disease or infirmity" (World Health Organisation, 1948). The definition of health is the subject of debate (Saracci, 1997), but most assessments of health-related quality of life include physical and psychological components. For example, the widely used and highly regarded 36-Item Short-Form Health Survey (SF-36) includes questions on physical functioning, social functioning, role limitations due to physical problems, role limitations due to emotional problems, mental health, energy/vitality, pain, and general health perception (Jenkinson, Stewart-Brown, Petersen, & Paice, 1999). Disease refers to the temporary or permanent impairment of physical or mental function. The definitions of health and disease had no bearing on the present review because the search strategy we used was designed to capture relevant studies.

The systematic review

This systematic review was conducted in accordance with best practice, namely the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) (Moher, Liberati, Tetzlaff, & Altman, 2009). We searched PubMed, Scopus, and Web of Science using the following search terms: swimming (MeSH term), swimming pools (MeSH terms), water sport (title/abstract), aquatics (title/abstract), competitive swimming (title/abstract), health (MeSH term), wellbeing (title/abstract), disability (title/abstract), cognition (title/abstract) [MeSH is Medical Subject Headings and MeSH terms are used to search electronic databases (U S National Library of Medicine, 2015)]. The populations in the search included able-bodied and disabled people of any age, gender and ethnicity. The interventions in the search included any type of swimming where competition was clearly involved. The outcomes in the search included any health-related measure. The study designs in the search included all experimental and observational designs and reviews. Due to the anticipated heterogeneity in terms of study design, populations and outcomes, a quantitative synthesis (meta-analysis) was not deemed appropriate.

What is and is not included in this review

Sport England recognises swimming as a sport, including the disciplines of diving, long distance swimming, open water swimming, synchronised swimming, and water polo (Sport England, 2016d). Sport England does not distinguish between swimming as a sport and swimming as a disability sport (Sport England, 2016d). Evidence of the benefits of swimming and its disciplines was included in this review if competition was clearly involved. Competition is an integral component of sport (Council of Europe, 1993) and evidence was not included if competition was not clearly involved. Swimming is exercise when it does not involve competition (Bouchard & Shephard, 1994; Caspersen et al., 1985).

Defining the type and strength of evidence

Evidence statements were produced on the health and wellbeing benefits of swimming as a sport. We specified the type (A to D) and strength (1 to 3) of evidence in support of each statement using widely recognised definitions (Table 1) (National Cholesterol Education Program, 2002). Research studies can be divided into experimental and observational designs. Experimental studies offer the most compelling evidence. The randomised, controlled trial (RCT) is considered to be the strongest design. In a RCT, participants are randomly assigned to intervention or control groups and each group is monitored. The nature of the RCT is such that differences between the groups at the end of the study can be directly attributed to the intervention.

Table 1.
Categories of evidence type and strength

Category	
Type of evidence	
A	Major RCTs
B	Smaller RCTs and meta-analyses of other clinical trials
C	Observational and metabolic studies
D	Clinical experience
Strength of evidence	
1	Very strong evidence
2	Moderately strong evidence
3	Strong trend

*From the US National Cholesterol Education Program (National Cholesterol Education Program, 2002). RCT is randomised, controlled trial. Some definitions include a fifth category, anecdotal and testimonial evidence. Such evidence is not reliable, however.

Results

Summary of the evidence

The figure shows the selection of the 73 studies included in the present review. In agreement with a previous review of the evidence published from 2003 until the end of April 2013, we found no experimental evidence of the health and wellbeing benefits of swimming as a sport (Oja et al., 2015). The benefits of swimming were investigated in adolescent females with intellectual disabilities (Ninot, Bilard, & Delignieres, 2005); however, a true experimental design was not used. We found four cross-sectional studies in which chronic disease risk factors were better in swimmers than others (Climstein et al., 2016; Guthrie, Erickson, & Lau, 2013; Smith, Mendez, Druckenmiller, & Kris-Etherton, 1982; Walsh et al., 2013). It is noteworthy that, compared with the general population, body mass index was lower in 527 masters swimmers (Walsh et al., 2013), the prevalence of high blood pressure was lower in 1,346 masters swimmers (Guthrie et al., 2013), and cholesterol concentrations were better in 1,435 masters swimmers (Climstein et al., 2016). We also found one observational study (Rubin, Lin, Curtis, Auerbach, & Win, 2013) and one review of observational studies (Rubin & Rahe, 2010) about the performance of masters swimmers. Physical fitness, or the ability to perform physical activity, was high in the masters swimmers. Low physical fitness is one of the strongest predictors of mortality (Ross et al., 2016). We found no evidence that the risk of injury was different in swimming than other sports, though the main purpose of the review was not to investigate risk of injury.

Evidence statements

We offer three evidence statements. First, there is no experimental evidence of the health and wellbeing benefits of swimming as a sport. Second, there is observational evidence that chronic disease risk factors are better in masters swimmers than the general population (evidence type: C; evidence strength: 2). Third, there is observational evidence that physical fitness, or the ability to perform physical activity, is high in masters swimmers (evidence type: C; evidence strength: 2).

Discussion

Interpretation of the evidence

Experimental studies offer the most compelling evidence and the RCT is considered the strongest study design. We found no RCTs in this review. We did find four cross-sectional studies in which blood pressure and other chronic disease risk factors were better in masters swimmers than the general population. We also found one observational study and one review of observational studies in which physical fitness, or the ability to perform physical activity, was high in masters swimmers. This is an important finding because low physical fitness may be a stronger predictor of mortality than smoking, high blood pressure, and other traditional risk factors (Ross et al., 2016). More RCTs and more observational studies are needed to support the notion that swimming as a sport is beneficial to health and wellbeing.

Lessons from football

Competition is an integral component of football, whether it is casual or organised football. Therefore, there is no danger of misclassifying football as exercise. In a review of the evidence published from 2003 until the end of April 2013, 18 studies about football were found and it was calculated that the sport improved aerobic fitness, resting heart rate, and body fat (Oja et al., 2015). Eight studies about swimming were found, but there was insufficient data to calculate the benefits (Oja et al., 2015). Furthermore, it was unclear whether swimming was a sport (involving competition) or an exercise (not involving competition). Data from more than 80,000 adults in the Health Survey for England and the Scottish Health Survey suggest that, compared with those who reported participating in no sport and exercise, cardiovascular disease mortality risk was 41% lower in those who reported participating in swimming (data were collected in 1994, 1997, 1998, 1999, 2003, 2004, 2006 and 2008 in England and in 1995, 1998 and 2003 in Scotland) (Oja et al., 2016); however, it was again unclear whether swimming was a sport or an exercise.

The Football Fans in Training programme shows how football and football clubs can offer health benefits. Best practice was followed in developing the programme (Gray et al., 2013). Then, a RCT was conducted to evaluate the programme (Hunt et al., 2014). Some 750 overweight football fans aged 35 to 65 years took part in the trial. Half of them took part in a 12-week weight management and physical activity programme that was delivered by club community coaches in 13 Scottish professional football clubs. The physical activity programme included walking and small-sided football games. After 12 months, it was found that those in the programme lost around five kilograms more in weight than those not in the programme (Hunt et al., 2014). Such weight loss is sufficient to halve the risk of type 2 diabetes (Knowler et al., 2002). The Football Fans in Training programme was such a success that it is being evaluated in 1,000 men in four countries (van Nassau et al., 2016).

The success of the Football Fans in Training programme begs the question, is it possible to develop and evaluate an intervention to engage physically inactive swimming fans in lifestyle change? Football fans are a passionate group (Bunn, Wyke, Gray, Maclean, & Hunt, 2016) and the idea behind the programme was that men's loyalty to their football team would encourage them to sign up. There are 40 swimming club networks in England and a further 46 networks are being developed (The ASA, 2016). New events have been added to the calendar and more than 15,000 spectator tickets were sold in 2015 (The ASA, 2016). There are also guidelines for designing and evaluating novel interventions (Craig et al., 2008). Therefore, it should be possible to develop and evaluate an intervention to engage physically inactive swimming fans in lifestyle change. It is for Swim England (formerly the Amateur Swimming Association) and other stakeholders to take up the challenge of turning the Football Fans in Training Programme into the Swimming Fans in Training Programme. The delivery and evaluation of the postulated Swimming Fans in Training Programme would give Swim England an opportunity to demonstrate the health benefits of swimming as a sport, which is now the basis of government policy on sports funding (HM Government, 2015; Sport England, 2016e). Interestingly, the Football Fans in Training programme is currently being adapted to hockey (Gill et al., 2016).

The role of technology

Millions of physical activity monitors, or fitness trackers, are sold each year (The Guardian, 2015a); And, millions of health and fitness apps are downloaded each year (The Guardian, 2015b). In the UK government report, Sporting Future, it is suggested that, "Wearable technology encourages people to be more physically active through quantifying their activity or competition" (HM Government, 2015). There is little experimental evidence of the health benefits of wearable technology (Jakicic et al., 2016). Nonetheless, the Amateur Swimming Association has acknowledged that swimming "has fallen behind when incorporating technology into the experience" (The ASA, 2016). Some activity monitors measure swimming, but most do not. There are some swimming apps, but many more running and cycling apps. Individuals and teams can readily compete in virtual runs and virtual bike rides, but there are few virtual swimming challenges.

The incorporation of wearable technology into swimming would allow the quantification of swimming performance for health and would facilitate goal setting and self-monitoring of swimming performance. Such variables may previously have been captured using manual methods such as a stopwatch held by a coach; however, such methods may be prone to human error and may not be available to non-elite swimmers. Common metrics provided by swimming sensors include stroke counting, speed calculation and SWOLF (strokes per length – a measure of efficiency) (de Magalhaes, Vannozzi, Gatta, & Fantozzi, 2015). The ability to automatically capture these metrics allows the swimmer or their coach to self-monitor performance and therefore provides a potent feedback loop to improve performance. The incorporation of wearable technology in this way may also drive technological innovation, including improved form factors, increased battery life, and greater functionality. Such innovations may lead to greater adoption of wearable technology for recreational and competitive swimming. Similar to the wider wearable technology sector, many swimming sensors are wrist based; although, several are available which can be worn in a swimming cap (Mooney et al., 2015).

Novel and emerging technology

The limited research to date indicates that these sensors are more suited to competitive swimmers than recreational swimmers (Mooney et al., 2017). This is due to the algorithms used to process the acceleration data into useful metrics; these algorithms are susceptible to variations in swimming technique and may therefore be more robust with the more optimal technique found in competitive swimmers (Mooney et al., 2017). Disruptive innovations in wearable technology for swimming include the use of artificial intelligence; selected novel and emerging technologies in the swimming sector is are shown in Table 2. The selection is shown to illustrate the type of new technologies that are beginning to emerge around the world and the range of metrics they provide. Many of these technologies are novel and have not undergone rigorous, scientific testing. Therefore, we are unable to comment on validity and reliability. We would expect these developments to improve the utility of swimming sensors in the coming years. Given the constant innovation in wearable technology, we would expect the technologies outlined here to be improved upon or supplanted within 18-24 months.

Table 2.
Novel and emerging technologies in swimming*

Device	Wear site	Metrics
Tritonwear™	Swim cap	Stroke type, time underwater, distance per stroke, speed, push off force, efficiency, pace time, splits, breath count, stroke rate, stroke count, turn time
XMetrics™	Swim cap	Total time, split time, target time, total laps, split laps, pacer, pause counter, pause duration, restart time, calories burned, rest time, total distance, average pace, interval detection, time per lap, pace per lap, strokes per lap, stroke frequency, distance per stroke
Misfit Shine 2 Swimmer's Edition™	Wrist	Swim laps, steps, calories burnt, distance, sleep patterns, quality and duration
Avidasports™	Head, wrist and ankle	Tempo, stroke count, breakout, distance per stroke, average speed, split times, kick count, kick tempo.
Swimovate poolmate™	Wrist	Total time, total lengths, total metrics, total calories, average strokes, time per set, lengths per set, metres per set, average strokes, average speed, average efficiency
Garmin Forerunner 920XT™	Wrist	Lengths, distance, pace, stroke count, stroke rate, calories, stroke recognition, pool lap recognition, swim workouts, stroke efficiency, automatic intervals, rest timer, open water swim distance.
Finis Swimsense™	Wrist	Total laps, time intervals, pace, distance per stroke, calories, SWOLF, intervals, distance per stroke.
Polar V800™	Wrist	Swimming style, distance, pace, strokes, rest time, SWOLF.

*This table was not produced in a systematic fashion, but is illustrative of the current state of the art. The authors do not endorse any particular company or device. SWOLF is strokes per length, a measure of efficiency.

In addition to the use of wearable technology to provide swimming metrics, another important avenue relates to the use of virtual challenges. A virtual challenge might include an online platform and community to bring together swimmers and swimming enthusiasts for a swimming competition, even when they are in different places. Swimmers might 'race' by trying to complete a challenge, such as swimming a certain distance in the fastest time. Swimmers' scores are then compared and the race is won by the participant with the fastest time. Virtual challenges are designed to be completed anywhere and anytime. Such challenges offer the potential to introduce a competitive element and thereby move swimming from an exercise to a sport. These challenges are currently more prevalent for running and cycling, but offer the potential for swimmers to compete against fellow swimmers in a simple and convenient way. Wearable technology could also be incorporated into virtual swimming competitions, by providing an objective measurement of swimming length and time to completion; the alternative being manual entry of swimming length and time by the swimmer. This objective, automatically uploaded information would give the confidence that the competitor was not trying to cheat the system. This information might also provide another powerful market opportunity for wearable technology manufacturers and, as previously described, drive innovation in the sector.

Injury and illness

It is hard to estimate the rate of injury in a given sport because a large number of participants have to be followed for a long period of time. It is harder still to compare the rate of injury in different sports. The evidence suggests that high training loads increase the risks of injury and illness in swimmers and other competitive athletes (here, injury and illness refer to impairments in performance, including reports of soreness in a joint, reports of injuries by qualified medical practitioners, reports of injuries by unqualified medical practitioners, and reports of time lost from training or competition) (Drew & Finch, 2016). The female athlete is also susceptible to the female athlete triad, a medical condition consisting of three components: low energy availability with or without disordered eating; menstrual dysfunction; and, low bone mineral density (De Souza et al., 2014). In a study of 323 collegiate athletes from 16 sports, the sports with the highest proportions of athletes classified with moderate risk or high risk of the triad were gymnastics (56%), lacrosse (50%), cross-country running (49%), swimming and diving (43%), sailing (33%), and volleyball (33%) (Tenforde et al., 2017). It is recommended that athletes' training and competition loads are routinely monitored and that athletes' injuries and illnesses are accurately recorded to better understand the relationships between sports participation and injury and illness (Drew & Finch, 2016). It is also recommended that athletes with elevated risk of the female athlete triad receive medical treatment, including assessments of nutrient intake and menstrual function (De Souza et al., 2014). Swimming per se is advocated because it is a low-impact physical activity (Just Swim, 2016). Low-impact activity might be appropriate in the rehabilitation of injury, but, contrary to popular opinion, weight-bearing exercise is beneficial to bone health (Francis, Letuchy, Levy, & Janz, 2014; Julian-Almarcegui et al., 2015; Shephard, Park, Park, & Aoyagi, 2016).

The impact of London 2012 on swimming participation

There is conflicting evidence of the impact of major events on sports participation (Sport England, 2012a; The Guardian, 2017b). On the one hand, for example, 70% of those who attended a major sporting event aged 25 or under felt inspired to participate or participate more often. On the other hand, for example, only 7-15% of adults in the UK were inspired by the London 2012 Olympic and Paralympic Games to actually play more sport. There was a small increase in swimming participation between October 2007-October 2008 and October 2011-October 2012 (Department for Culture, Media & Sport, 2013); however, there was no lasting impact on participation in the general population (Sport England, 2016b). The games improved attitudes towards disabled people and there was an increase in sports participation, at least in the short term (Department for Culture, Media & Sport, 2013). Although swimming is the most popular sport among adults with a disability (Sport England, 2016c), some 50% of those with three or more impairments were inactive compared with 21% of those without a disability in 2015-2016 (Sport England, 2016a).

It is hardly surprising that the 'win at all costs' approach has been questioned (The Guardian, 2017a). The UK government could have invested in large-scale physical activity interventions that work (Reis et al., 2016). The government could also have made the facilities freely available after the games. For example, the city of Medellín in Colombia hosted the South American Games and the FIFA U-20 World Cup and anyone can now use the swimming pool and the rest of the Atanasio Girardot Sports Complex free-of-charge. This strategy of 'recycling and re-purposing' major sporting facilities into major community facilities warrants serious consideration elsewhere because it leaves a legacy of physical activity and health.

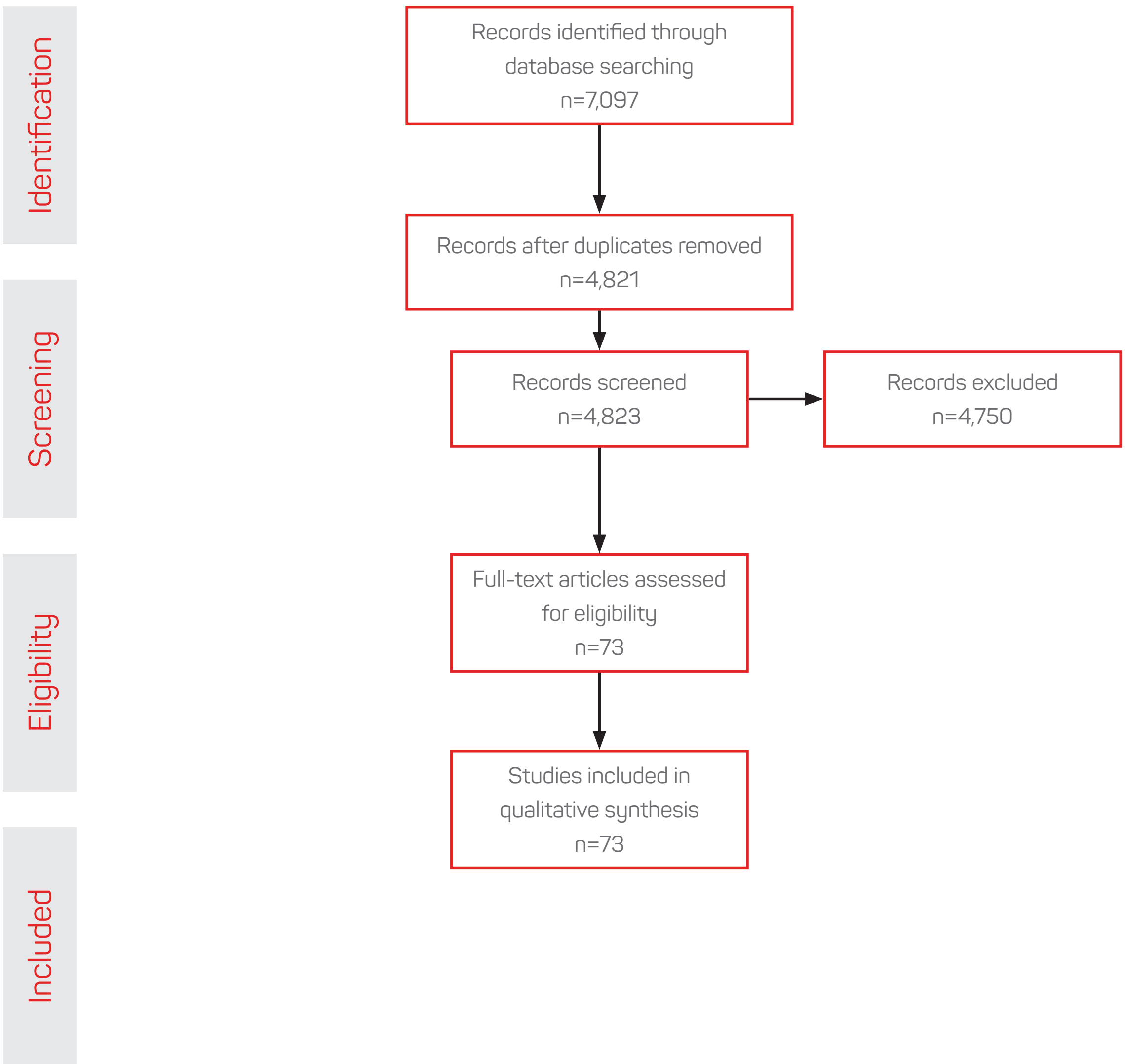
Recommendations for future research and sport policy

Almost 70,000 people take part in swimming competitions in England (The ASA, 2016). However, the UK government has said that it will change the way sport is funded, so that, "It is no longer merely about how many people take part, but rather how sport can have a meaningful and measurable impact on improving people's lives" (HM Government, 2015). Therefore, it is imperative that the health and wellbeing benefits of swimming as a sport are investigated without delay. We would recommend that Swim England and the academic community consult with swimmers, swimming clubs, schools, local government, national government and other stakeholders to identify important research questions. Randomised, controlled trials provide the strongest evidence and we would recommend that best practice were used in designing and evaluating any interventions (Craig et al., 2008; Schulz, Altman, & Moher, 2010). When best practice in designing and evaluating interventions is not followed, the resulting evidence is of such poor quality that is suggests that exercise training offers no health benefits (Pavey et al., 2011). It would also be helpful if investigators were to publish their methods. For example, it would be helpful if Sport England were to publish the methods used to design and evaluate the female sport intervention, This Girl Can. Similarly, it would be helpful if Swim England were to publish the methods used to design and evaluate the disability sport intervention, Let's Go Swimming. Surveys also provide a valuable source of evidence and, to avoid misclassification, we would recommend that researchers were to distinguish between swimming as a sport and swimming as an exercise. Evidence gathered from RCTs and surveys should be used to demonstrate the health benefits of swimming as a sport and, thus, to justify investment in swimming as a sport.

Summary and conclusions

There is little evidence of the health and wellbeing benefits of swimming as a sport. Swimming is a popular sport; however, the government has made it clear that its funding is in jeopardy if it cannot be shown that it improves people's lives. Randomised, controlled trials provide the strongest evidence and should be conducted. Surveys provide valuable information and researchers should distinguish between swimming as a sport and swimming as an exercise.

Figure.
The selection of studies included in the review



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Chapter 7

Swimming for health and wellbeing: the economic case

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Introduction

As previous chapters have shown; swimming is a healthy, non-weight bearing physical activity (PA) that can be undertaken by almost anyone.

Indeed, despite a dramatic decline in popularity since 2005, in the year to September 2016 some 2.5 million people aged 16 and over (5.67%) reported swimming once a week for at least 30 minutes (Sport England, 2016). This chapter presents an economic case for swimming and aims to (a) demonstrate the potential of swimming in contributing to meeting physical activity recommendations, and (b) outline the evidence of interventions designed to increase swimming participation and their value for money.

Uptake of swimming in England and elsewhere

Noncommunicable diseases (NCDs) or long term health conditions including cardiovascular diseases are estimated to consume some 70% of the National Health Service budget (NHS, 2014). Meeting the United Kingdom (UK) Chief Medical Officers' (CMO) guidelines of at least 150 minutes of moderate activity per week (or 75 minutes of vigorous activity) reduces the incidence of almost all of these diseases by 20-40%. Further recommendations are made relating to muscle strengthening, balance and reducing time being sedentary (Department of Health, 2011). Perhaps the most notable effect of PA is the estimated reduction in type 2 diabetes of 30 – 40%; itself a health condition that costs the NHS 10% of its annual budget - £1.5 million per hour (Diabetes UK, 2017). The Health Survey for England (2012), timed to coincide with the 2012 London Olympic Games, found that 34% of males and 44% of females aged 19 and over did not meet recommended activity levels (Craig and Mindell, 2014). In addition, 64.8% of those aged 16+ in England are either overweight or obese (Public Health England, 2015). Obesity is frequently associated with musculoskeletal disorders often precluding and/or contra-indicating weight-bearing physical activity. Swimming may therefore offer an avenue to PA where other PA options and opportunities prove inaccessible (Gappmaier et al., 2006).

Despite this evidence and local opportunities to swim, swimming participation is low (about 11% based on Active People Survey (2012-13) and varies by gender, age, ethnicity, socio-economic status, parent /guardianship and English region. Females are more likely to report having swum in the previous four weeks than males (12.8% v 8.3%), participation almost halves in those aged 55+, those self-identifying as Chinese are almost twice as likely to swim than Asians, and swimming is more common in those of a higher socio-economic status and more common in those with children. Participation is slightly higher in the South and London than other English regions (Table 1).

Table 1.
Swimming participation by demographic and socio-economic characteristics.

Characteristics of swimming population in England	Number (% of population)
Gender	
Male	5,548 (8.29)
Female	12,539 (12.77)
All	18,087 (10.95)
Age	
16 – 34	3,684 (14.34)
35 – 54	7,847 (14.59)
55+	6,292 (7.52)
Missing	264 (12.62)
Ethnicity	
White	16,872 (11.25)
Mixed	172 (10.69)
Asian	339 (7.16)
Black	187 (5.44)
Other	88 (11.76)
Chinese	26 (13.13)
Missing	403 (9.02)

Characteristics of swimming population in England	Number (% of population)
Socio-economic status NS SEC 1 – 4 NS SEC 5 – 8 NS SEC 9 Missing	 11,896 (12.80) 4,095 (7.87) 1,832 (10.09) 264 (12.62)
Number of children in household None One or more Don't know / missing / refusal	 10,761 (9.03) 6,567 (17.03) 759 (10.20)
Region North East North West Yorkshire West Midlands East Midlands East South West South East London	 627 (10.31) 2,177 (10.73) 1,081 (10.12) 1,595 (10.48) 2,057 (10.11) 2,538 (10.62) 2,157 (11.77) 3,946 (11.61) 1,909 (11.67)

Source: Analysis of Active People Survey (2012-13)

Making international comparisons is difficult as physical activity questionnaires will vary by design, sample size, age and sports included (Gratton, Rowe and Veal, 2011). It should also be noted that for many swimming is not only a sport or means of recreation but a potentially life-saving skill; drowning is the 3rd leading cause of death from unintentional injury worldwide accounting for 7% (320,000) of all injury-related deaths. Even this is likely to be an under-estimate as it does not include drownings through flooding (World Health Organisation, 2016). There is a considerable literature estimating the Value of a Statistical Life (VSL). For example,the cost that might be attributed to reducing the risk of one statistical death (Andersson and Treich, 2011). However, it is conservatively estimated that the global cost of drowning is some $146.9 billion a year (Frontier Economics, 2015). The World Health Organisation therefore recommends learning to swim as a public health measure (World Health Organisation, 2014).

As a sport, swimming is one of the top 10 activities undertaken during free time in Africa, the Americas, the Eastern Mediterranean, Europe, Southeast Asia and the Western Pacific. In adolescents (aged 13 – 17) it is one of the top five activities in Africa, the Americas, the Eastern Mediterranean, Europe, and the Western Pacific and one of the top 5 activities for children (aged 5 – 12) in the Americas, Europe and the Western Pacific (Hulteen et al., 2017). A lack of studies precludes more detailed rankings. Similarly, data issues including survey methodology, representativeness and only being available at province or for particular ages makes robust conclusions difficult but it is apparent that swimming participation declines with increasing age, with highest participation rates in adults in Europe, in Eastern Mediterranean, in adolescents, and in the Western Pacific in children (Table 2).

Table 2.

Adult, adolescent and child swimming participation rates by WHO region

	Adult (aged 18+)	Adolescent (aged 13 – 17)	Child (aged 5 – 12)
Europe	7.8 (4.8 – 12.4)	9.0 (4.8 – 16.2)	10.3 (2.3 – 35.)
Americas	4.5 (2.0 – 9.8)	14.9 (6.6 – 30.1)	15.7 (3.4 – 49.9)
Eastern Mediterranean	6.4 (0.8 – 35.0)	32.0 (23.3 – 42.1)	No data
Africa	1.7 (0.6 – 4.9)	6.2 (0.4 – 52.7)	No data
South-east Asia	0.6 (0.0 – 40.0)	No data	No data
Western Pacific	4.4 (2.1 – 9.1)	17.7 (4.7 – 48.3)	33.9 (5.4 – 82.1)

Source: Global Participation in sport and leisure-time physical activities: A systematic review and meta-analysis. Ryan M. Hulteen, Jordan J. Smith, Philip J. Morgan, Lisa M. Barnett, Pedro C. Hallal, Kim Colyvas, David R. Lubans. Preventative Medicine 95 (2017) 14-25

Link between swimming and physical activity

Several studies have attempted to understand the effect of swimming on levels of PA. This research was extremely heterogeneous: varying by study design (survey analysis, intervention studies including a randomised control trial (RCT)), recruitment (national surveys, community advertising, referral by healthcare / education professionals, self-referral), population (age, weight, country, inclusion of parents / guardians or carers), measurement (self-report, commercial data, number of swims, Metabolic equivalent (MET) minutes / week) and outcome measures (PA, Body Mass Index (BMI), waist circumference).

Swimming appears to be an effective means of increasing PA in children. In Belgium, pupils aged 8-12 years engaged more in moderate-to-vigorous physical activity (MVPA) during swimming classes (51% ± 9.9) than during non-swimming physical education (PE classes (40% ± 17) ($p< 0.01$). However, it also found that due to travel and changing times only 38% of the allocated PE time was spent actually swimming compared to 72% of non-swimming PE time (Cardon et al., 2004).

The Mind, Exercise, Nutrition, Do-it (MEND) programme was introduced to combat childhood obesity through targeting families with a programme that included 18 two-hour education and PA sessions followed by a 12 week free swimming pass. RCT evidence showed that waist circumference reduced by 4.1 cm and BMI by 1.2 kg/m^2. However, only 32% of families used the free swimming pass and at a low frequency making it difficult to attribute the effect to swimming alone (Sacher et al., 2010).

In Bucharest, Romania, swimming three times a week for 40 minutes combined with a low-calorie diet among students aged 18-25 years was compared to swimming only once a week for seven months. Whilst reductions in BMI were observed, it is unclear whether this was attributable to diet, swimming or a combination of the two (Ganciu, 2015). The highly specific population also makes it difficult to generalise this study to other populations. Further, it is adherence to either the programme or diet in control and intervention groups is unclear as well as is any effect of PA undertaken outside the programme making conclusions difficult.

In Guadeloupe, 160 people with 'moderately incapacitating chronic diseases aged 50+ and categorised as of low PA together with 39 care-givers were recruited to 10 weeks of professionally supervised swimming lessons. Pre- and post-intervention data indicated a significant improvement in PA category in the 77 patients who provided data at all time points (Antoine-Jonville et al., 2013).

The 2012 – 2013 Active People Survey (APS) has been used to quantify the contribution of utility cycling to the probability of meeting physical activity guidelines (Stewart, Anokye and Pokhrel, 2015). Applying the same methodology showed that individuals who swim are 2.8 times more likely to meet physical activity guidelines than those that do not. However, swimming is undertaken in a medium that is denser than the surrounding environment and can therefore require more physical effort than land-based activity e.g. it is more likely to become vigorous rather than moderate activity. Applying the same methodology as Stewart et al. (2015) and following Chief Medical Officer guidance that vigorous PA 'counts double' towards meeting PA guidelines (Department of Health, 2011), we estimate that those who swim for recreational or competitive purposes are eight times more likely to meet PA guidelines.

Increasing participation

Swimming pools require considerable investment and include plant operations that operate continuously 24 hours / day for 365 days / year (Sport England, 2013). Given the above health and economic benefits it would seem sensible to maximise swimming wherever possible. However, the pool entrance charges could be a barrier (Steenhuis et al., 2009). Modelling of those who had undertaken physical activity in the Health Survey for England (HSE) 2008 found that participation in PA was negatively associated with cost and travel time with the greatest effect found for swimming. Here a 10% increase in entrance fee was associated with a 29% drop in occasions of swimming but that a 10% higher monthly price was associated with 1% fewer occasions of swimming (Anokye, Pokhrel and Fox-Rushby, 2014).

In 2007 in the run-up to the 2012 London Olympic Games the Department for Culture, Media and Sport (DCMS) committed to making the UK a 'world-leading sporting nation' with 'improved access to more, better quality sports and leisure facilities at the heart of every community to make leading a healthier, more active lifestyle easier' DCMS, 2008). In 2008, the Free Swimming Programme (FSP) was launched, funded by £140m from five Government departments, to encourage Local Authorities (LA's) to offer free admission to publicly owned swimming pools for people aged 60 and over and 16 and under. In the first year of the programme, 197 LA's offered free swimming to both those aged 60+ and those aged 16 and under whilst 64 only offered free swimming to those aged 60+ (PricewaterhouseCoopers LLP, 2010).

The FSP has been evaluated at both a national (PricewaterhouseCoopers LLP, 2010) and local level (Kokolakakis, Pappous and Meadows, 2015; Pringle et al., 2014; Audrey et al., 2012). Nationally the FSP was evaluated through an online survey, analysis of monthly monitoring data submitted by participating Local Authorities and where possible through the Active People Survey (APS), which did not include those aged under 16 until 2012. Analysis accounted for a number of effects including extra participation by those aged 17-59 years accompanying the targeted age groups ('additionality'), those who would have swum without the introduction of the FSP (deadweight), swimmers in the target groups 'crowding out' other age-groups (displacement), national trends and additional swimming replacing other forms of PA (substitution).

Consequently, it is estimated that there were an additional 5.52 million swims in those aged 16 and under and an additional 1.49 million swims in those aged 60 and over. 81.6% of those aged 16 and under reported that swimming had not resulted in less time being spent in other forms of PA compared to 85.6% of those aged 60 and over. Similarly, the free swim initiative in Wales was found to increase participation in the same targeted groups (Bolton et al., 2008).

Evaluation of FSPs at a local level found more nuanced effects; in young people receiving a 'free swim' pass in a 'city in the South West of England' participants were categorised into four categories of levels of PA with pre-post data collected from 245 participants. No change in PA category was found because of the programme (Pringle et al., 2014). In a 'local community in the south-east of England data was collected from four leisure centres and the APS used to assess the effect of the FSP programme on the population as a whole. Here it was found that whilst the impact of free swimming was positive for those aged under 11 and over 60 it declined in those aged 11 – 16 and 'adults' (17 – 59 years). 27,896 people registered for the scheme, (51% of the eligible population), 18,054 activated their card (used only once) with 72% of cardholders indicating that they were existing participants (Bullough, Davies and Barrett, 2015).

Equally, pricing policies therefore do not seem to be wholly effective in generating swimming participation; indeed, in Wales it was found that although free swimming had a positive impact on 'hard to reach groups' other factors such as location, times of availability, a desire to avoid over-crowded pools and a dislike of swimming were also important (Bolton et al., 2008). Similarly, in Bristol, the major determinants of uptake of a free swimming initiative offered to all young people aged 0 – 15 were age, gender, proximity to a swimming pool and warmer season (Audrey et al., 2012). Beyond the FSPs however there appears to be little research into what might increase swimming participation.

In summary, swimming is an activity that can be undertaken by almost anyone including those for who other forms of PA may be medically contra-indicated. PA itself is associated with a reduction in NCDs of between 20-40%. NCDs are costing the NHS some 70% of its budget. Despite this, approximately a third of the population does not meet PA guidelines and the past decade has seen swimming decline in popularity. Globally swimming uptake is not only a recreational activity but a recommendation of WHO as a means of preventing drowning, itself the 3rd greatest cause of unintentional injury. Aside from the human cost this is estimated to have an economic cost of $147 billion a year. Recreationally or as a sport swimming is extremely popular ranking as one of the top five activities undertaken during free-time in most regions across the globe. Data issues make robust conclusions difficult but it is apparent that participation declines with age. Nationally uptake is greater in females, those of higher socio-economic status, declines with age and has relatively little uptake in those of either Asian or Black ethnicity. There is greater uptake by those who have children in the household. Tentative conclusion may be drawn from studies indicating that amongst those who swim it is effective in increasing PA. This may relate to water being a denser medium than air thereby requiring more vigorous activity. However, initiatives to increase swimming participation through free swimming have had mixed results with some evidence of increased participation but relatively little success in encouraging new swimming participants.

Are UK swimming programmes good value for money?

To inform decision making, policy-makers will want to know the cost-effectiveness of swimming interventions. Few studies to date have examined the costs and benefits of swimming interventions and more specifically around the health and wellbeing benefits of swimming.

A cost-effectiveness analysis of free swimming programmes was undertaken prior to the inception of the FSP (Fordham and Barton, 2008). The authors compared walking buses, dance classes, a community sports scheme and swimming and found that free swimming programme was associated with a cost per Quality Adjusted Life Year (QALY) of £40,462. The cost/QALY was £4008 for walking buses, £27,571 for dance classes, £40,462 for free swimming and £71,456 for community sport e.g. only walking buses were found to below the £20,000 / QALY assumed to be the (then) acceptable threshold for the National Institute of Clinical Excellence (NICE). However, the authors acknowledge high levels of uncertainty having needed to make a number of unverified assumptions including the cost of the activity, numbers participating, changes in PA, the relationship between PA and the quality of life in children and what benefits might accrue to different populations and therefore caution against making exact cost-effective conclusions (Fordham and Barton, 2008).

A study analysing the cost effectiveness of nine interventions to increase PA in adults and children and young people (aged 10 – 17 years) not meeting the PA guidelines found that swimming cost a mean of £563 for one "completer". The cost per QALY of free swimming activities for young people in the community was £103 and for all nine interventions ranged from £47 (motivational interviewing) to £509 (exercise referral) far below the NHS acceptability threshold of £20,000 making the interventions cost-effective (Pringle et al., 2010).

An economic analysis of the national FSP programme estimated the effects of the programme on costs to the NHS and loss of productive days and found a benefit cost ratio (BCR) of 0.53:1 for those aged 60 and over and 0.82:1 for those aged 16 and under, for year one of the programme (PricewaterhouseCoopers LLP, 2010). Although these data showed the programme was not cost-effective in the short term (i.e. in one year), it is unclear however whether the long-term effects of swimming would have led to positive economic returns. In addition, this study includes several limitations including the self-reported nature of PA data from the previous year, potential for recall bias and an assumption of an attrition rate of approximately 10%. It also assumes an annual cost to the NHS of diabetes of £5.2 billion, approximately a third of the estimate of Diabetes UK of £13.7 billion (Diabetes UK, 2017).

In summary, few studies have assessed the cost-effectiveness of swimming interventions. Assumptions about the number of participants, effectiveness measure, longer-term effects have been key challenges / limitations in those analyses. As a result, findings from cost-effectiveness studies vary widely from being extremely cost-effective to ineffective. Therefore, assessing the cost-effectiveness of swimming programmes needs methodological improvements and further good quality research is needed for robust conclusions to be made.

Discussion

Physical activity is essential for health; the World Health Organisation (WHO) together with at least 20 countries have issued guidelines intended to address the 'pandemic' of physical inactivity; the fourth leading cause of death worldwide (Kohl et al., 2012).

Swimming would seem to be one means by which levels of PA can be raised; it is the most popular sport in England practised weekly by some 2.5 million people (Sport England, 2017) but also that with the highest 'latent demand' of people saying that they would like to swim, or swim more often (PricewaterhouseCoopers LLP, 2010). It is a non-weight bearing form of PA and it can be accessible to many with health conditions including obesity and musculoskeletal issues that may preclude other forms of PA. In 2015, there were approximately 5,060 separate swimming pool sites in England that did not require private membership, an increase of 564 since 2006. Despite this, participation fell by almost a quarter between 2005 and 2015. This may reflect a growth in 'wild swimming' (e.g. in lakes, rivers etc.), a greater reluctance to encourage swimming in schools, cuts to Local Authority budgets or even longer working hours but nonetheless this fall was seen in every English region (Rhodes, 2016).

FSPs seem to have increased swimming in both the Under 16 and Over 60 age-groups with over 80% of participants indicating that this extra swimming had not replaced other forms of PA. This may be a valuable approach to maintaining participation amongst existing swimmers but seems to be of limited value in attracting new participants. Indeed, evidence from targeting FSPs at or in deprived communities is that it does not seem to have resulted in dramatically increased uptake (Audrey et al., 2012). The overall effect of free swimming on PA rather than swimming is similarly ambivalent, at least in young people. In young people aged under 16 girls reported increased PA as a result of free swimming whereas no change was found for boys (Pringle et al., 2014) whereas in a population aged under 19 64% of participants reported more PA (Bullough, Davies and Barrett, 2015). Equally, in an obese population that might be expected to have most to gain from free swimming programmes uptake was limited (Sacher et al., 2010). The gains of PA are greatest in those who are most inactive (Department of Health, 2011) who are frequently those most disadvantaged in society (Gidlow et al., 2006). Free swimming targeted at deprived communities or obese populations does not seem to have resulted in large increases in PA, however. Beyond the FSPs there appears to be very little research into what interventions would either maintain or increase current levels of swimming participation at a population level, much less their cost-effectiveness. Given that once a week swimming participation in those aged 16 and over has fallen by 2.4% since 2005 (750,000 people) (Sport England, 2017) reasons for and to address this would seem to be an obvious gap in the academic literature as well as strategic community sport and leisure plans.

Summary and recommendations

Swimming is in many ways an ideal form of PA, accessible to many for whom other forms of PA are contra-indicated. It is also one of the few sports where female participation is greater than that of males. However, even in the face of Government support and an increase in provision; the health and economic benefits of swimming are not being realised. Once-a-week participation in those aged 16 and over has actually fallen by three-quarters of a million in the past decade.

Reasons for this are unclear; there is evidence that entrance pricing may maintain and / or increase participation in some populations but it is evident that the swimming 'offer' is failing to resonate with an increasing proportion of the population. If the Swim England vision of 'more people learning to swim, more people swimming regularly and more medals on the world stage' is to be realised then further work is needed to understand how to ensure that swimming continues to be the nation's most popular sport. Indeed, there is a notable lack of research into swimming uptake, maintenance and drop out across all populations including those that might benefit most. This includes those aged 17 – 59 i.e. those who might be expected to comprise the majority of the swimming population. There is little evidence of learning from international best practice or indeed other sports such as athletics which has increased participation by 50% since 2005.

Given the large capital costs of building the 5000 pools in England and very limited cost-effectiveness evidence on swimming interventions, more economic analyses on the costs and benefits of swimming are required. Future cost-effectiveness studies therefore will help decision makers to justify such investment and, more importantly, encourage further resource allocation in this ideal form of PA. Learning from existing economic analyses, it is important that future cost-effectiveness analyses should consider incorporating: (a) long-term health effects and healthcare costs; (b) wider outcomes, e.g. productivity benefits and benefits seen in other sports when used as a diversion from crime; and (c) adverse effects. These analyses should consider a trajectory that would allow explicit consideration of changes in activity levels over time. Future pragmatic/clinical trials and other types of studies evaluating swimming interventions should include economic analyses. The focus of such studies should be to establish what works (type of interventions), in which populations, in addition to demonstrating the short, medium and long-term value for money of various swimming interventions.

Legend

BMI – Body Mass Index. BMI is calculated by dividing an adults weight in kilograms by their height in metres squared (kg/m^2). BMI is categorised as the following:

Classification	BMI (kg/m^2)	
	Principal cut-off points	Additional cut-off points
Underweight	<18.50	<18.50
Severe thinness	<16.00	<16.00
Moderate thinness	16.00 - 16.99	16.00 - 16.99
Mild thinness	17.00 - 18.49	17.00 - 18.49
Normal range	18.50 - 24.99	18.50 - 22.99
		23.00 - 24.99
Overweight	≥25.00	≥25.00
Pre-obese	25.00 - 29.99	25.00 - 27.49
		27.50 - 29.99
Obese	≥30.00	≥30.00
Obese class I	30.00 - 34.99	30.00 - 32.49
		32.50 - 34.99
Obese class II	35.00 - 39.99	35.00 - 37.49
		37.50 - 39.99
Obese class III	≥40.00	≥40.00

Source: http://apps.who.int/bmi/index.jsp?introPage=intro_3.html Site accessed 4th March 2017

Metabolic Equivalents (MET). Physical activity is measured in METs e.g. the energy it takes to sit quietly. For the average adult, this is about one calorie per kilogram of body weight per hour. Moderate intensity activity is those that used 3 – 6 METS and vigorous activities more than 6 METs.

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Sources of further information and support

Swim England
www.swimming.org/swimengland

Swim England Strategy 2017-2021
www.swimming.org/swimengland/swim-england-strategy

UK physical activity guidelines for all ages
www.gov.uk/government/publications/uk-physical-activity-guidelines

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