Picking up the pace

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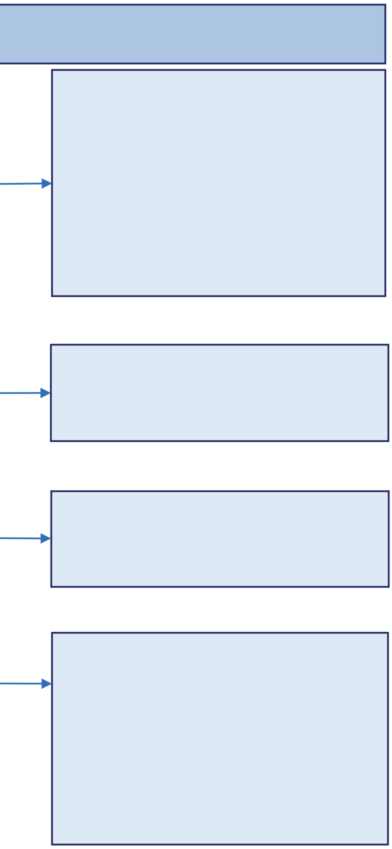
Chapter 7

Pacing in lane-based head-to-head competitions: a systematic review on swimming



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Abstract

Athletes' energy distribution over a race (e.g. pacing behaviour) varies across different sports. Swimming is a head-to-head sport with unique characteristics, such as propulsion through water, a multitude of swimming stroke types and lane-based racing. The aim of this paper was to review the existing literature on pacing behaviour in swimming. According to PRISMA guidelines, 279 articles were extracted using the PubMed and Web of Science databases. After the exclusion process was conducted, 16 studies remained. The findings of these studies indicate that pacing behaviour is influenced by race distance and stroke type. Pacing behaviour in swimming and time-trial sports share numerous common characteristics. This commonality can most likely be attributed to the lane-based racing set-up. The low efficiency of swimming, resulting from propulsion through the water, induces a rapid accumulation of blood lactate, prompting a change in swimmers' biomechanical characteristics, with the goal of minimising changes in velocity throughout the race. Although the literature on adolescent swimmers is scarce, young swimmers demonstrate a more variable pacing behaviour and have more difficulty in selecting the most beneficial energy distribution.

Keywords: pacing behaviour, swimming, athletic performance, psychology, adolescent, talent development.

1. Introduction

Pacing behaviour can be defined as the outcome of an individual's continuous, goal-directed, decision-making process regarding the distribution of energy resources over time (1, 2). In head-to-head and time-trial sports environments, the goal of the pacing process is to achieve optimal performance, which requires that athletes deplete all possible energy stores prior to finishing the race, but not so fast that a meaningful slowdown occurs before the end of the race (3, 4). The application of a broad range of theoretical models and the findings of experimental studies have shown that pacing behaviour is primarily influenced by the duration of the competitive event (3-5). In addition, recent studies have shown that different competitive environments influence pacing behaviour (6, 7). Lastly, in the finals of elite competitions in multiple sports, the pacing behaviour of more successful performers seems to differ from that of less successful performers (8, 9). The representation of an athlete's pacing behaviour can be termed the 'pacing profile'. Although general pacing profiles have been distinguished (10), it is assumed that pacing behaviour is associated with the different biomechanical and physiological limitations of the athlete (11) as well as with the different competitive environments (7, 12) the athlete competes in. Although the pacing process is already present in some form in young children (13), the brain areas associated with pacing behaviour continue to develop throughout adolescence (1, 14-16). Studies have shown that pacing behaviour develops during adolescence in elite athletes (17, 18). Moreover, adolescent athletes whose pacing profiles resemble profiles of adult elite performers earlier on in their development seem to achieve a higher performance level in their later careers compared to their peers (18). Therefore, an exploration of how adolescent athletes pace their races and develop their pacing behaviour throughout adolescence is particularly salient.

Swimming is a head-to-head sport entailing a unique combination of characteristics. Firstly, swimmers propel themselves through water, which requires more energy than overcoming air resistance during running or cycling races (19, 20). Because of the extensive energy loss to the environment, it is essential for swimmers to reduce drag and optimise propulsion (21, 22). Increased propulsion can be achieved by increasing the number of strokes for a given distance, defined as the stroke rate (SR), or by increasing the distance covered per stroke, namely the stroke length (SL). Due to the propulsion through water, an increase in SR will induce an increase in drag and, therefore, an increase in the amount of energy lost to the environment (22). Hence, elite swimmers mostly increase SL and reduce drag compared with non-elite swimmers (22). It has been posited that to ensure an optimally paced race, a swimmer should minimise fluctuations in velocity throughout the race, thereby minimising energy loss to the environment in the form of drag (12, 22). Moreover, a key phase of the race is the underwater phase that follows the start and turns. During this phase, the highest race velocity is achieved due to the increased impulse following the dive or push-off from the wall and the decrease in drag as a result of the adoption of a streamlined body position (23, 24). Competitive swimming entails several different stroke types and various race lengths, each associated with a specific technical skill set and energetic demand (25-27). The race distance in a pool ranges from 50 m to 200 m for the breaststroke, backstroke and butterfly events and up to 1,500 m for freestyle races (28). In open water, races can range from 5 to 25 km (29). Moreover, pool swimming competitions are generally organised as a qualifying structure comprising heats, semi-finals and finals. A final characteristic is that during pool swimming events, the competitors are separated by lanes. Consequently, competitors do not have to compete to be positioned in the ideal line, as is common in other head-to-head competitions such as (track-) cycling, running, short-track speed skating or Boat Race rowing.

Because of the unique combination of characteristics in the sport of swimming, the pacing behaviour in swimming could deviate from those observed in other sports. The present review is aimed at offering insights into sport-specific pacing behaviour in swimming. The primary aim is to provide an overview of studies on this subject. As there is a wide range of distances covered in swimming events, each of which entails particular energetics and techniques, it was decided to focus on 100–800 m pool races. The duration of these events (the world records for the 100 m and 800 m freestyle races are 46.91 s and 452.12 s, respectively (28)) best match those of other sports, such as track cycling as well as short- and long-track speed skating, as described in the literature (8, 9, 11, 30, 31). In addition to providing an overview of the literature, potential factors that influence the pacing behaviour of swimmers were identified and discussed. As adolescence is a crucial phase of pacing behaviour development, a particular focus of the review is on studies that explore the pacing strategies of adolescent swimmers (aged 12–21 years).

2. Methods

Following PRISMA guidelines, the PubMed and Web of Science databases were searched for studies about pacing behaviour in swimming up to until April 2017 using the following combination of terms:

(1) Pacing (OR performance strategy* OR energy distribution* OR pacing behaviour* OR velocity profile)

AND

(2) Swim*

NOT

(3) Triathlon* OR Animal* OR Fish* OR Pacemaker* OR Bacter*

The inclusion terms focused on articles written in English and published in peer-reviewed journals, covering pacing behaviour in swimming in relation to performance. Therefore, all included articles described pacing profiles with outcome variables such as lap times or (normalised) velocity distribution over the race. Additionally, the variability of pacing profiles over multiple races, expressed as the coefficient of variation (CV), was analysed in several studies. To provide an extensive overview of the literature, included articles featured participants of all age groups and performance levels. The initial search yielded 279 articles. After duplicate studies had been discarded, a total of 244 articles remained. The titles and abstracts of the remaining articles were read and papers lacking relevant links to pacing behaviour in swimming were excluded, resulting in 22 potential articles. After reading the bodies of these remaining articles, six were excluded because the articles did not meet the inclusion criteria. Therefore, a total of 16 studies were reviewed (Figure 1). Quality assessment of the articles was performed following guidelines provided by Letts *et al.* (32). Articles with a score above seven were considered of good methodological quality. Pacing profiles have been described in previous studies using velocity expressed as a percentage of the mean velocity in the race (e.g., 'normalised velocity'). This method provides a way of comparing the profiles of participants whose performance levels, sex and age differ. To avoid any misinterpretation in the description of pacing profiles, the definitions of general pacing profiles provided by Abbiss and Laursen (2008) and adapted for swimming by Mauger, Neuloh, & Castle (2012) were used in the current review (10, 33). In a negative pacing profile, the velocity increases throughout the race. By contrast, velocity decreases in a positive pacing profile. In an even pacing profile, the velocity remains constant throughout the race. In a parabolic-shaped pacing profile, the velocity decreases after the initial phase of the race and subsequently increases in the final phase. Finally, the fast-start-even pacing profile is characterised by a high velocity in the initial phase, followed by a lower, constant velocity during the remainder of the race. To the authors' knowledge, there are no specific percentages determined in the literature whereby these pacing profiles can be quantified.

As the qualification of participant performance level varied throughout the different included articles, there was a need for a standard qualification system to compare the outcomes reported in the included articles properly. Therefore, performance levels were categorised based on the world record in the year of publication of the article. Participants were divided into three groups: elite, sub-elite and competitive. Elite swimmers were defined as those with performances within 110% of the world record (24). Sub-elite swimmers were defined as those whose total race time was 110–120% of the world record. Finally, competitive swimmers were defined as swimmers who performed in a competitive environment but whose total race time exceeded 120% of the world record.

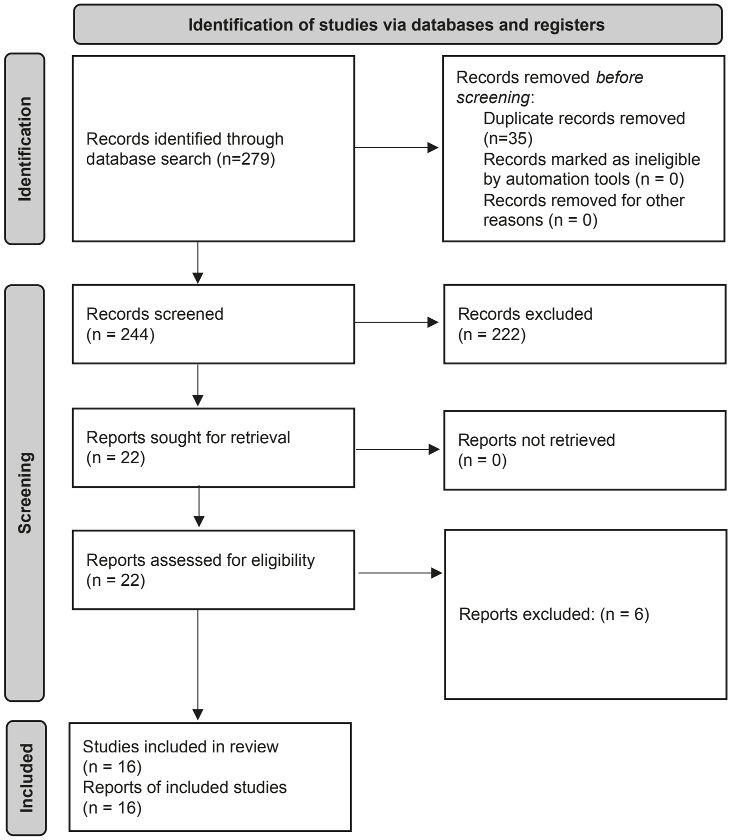

Figure 1. Flow diagram of the literature selection process, including the number of articles excluded at each stage.

3. Results

3.1. General pacing profiles

All of the reviewed articles (n = 16) were of good methodological quality (with total scores ≥ 7; Table 1). Therefore, studies were not distinguished based on qualitative weight. Table 2 presents a summary of the characteristics and outcomes reported in the reviewed articles. In the majority of studies, the participants were elite (n = 9), followed by sub-elite (n = 4) and competitive swimmers (n = 3). Most of the studies analysed freestyle swimming (n = 13), followed by breaststroke (n = 5), backstroke (n = 3) and butterfly (n = 3). The pool lengths were 25 m (n = 3), 50 m (n = 11), and not specified in two studies. The pacing profiles identified in the studies were positive (n = 11), negative (n = 2), even (n = 3), parabolic (n = 8) and fast-start-even (n = 8). In a majority of the articles (n = 11), pacing profiles were analysed using data collected during actual swimming competitions (e.g. 'real competition'). The articles which collected data in real competition analysed races from either a combination of the heats, semi-finals and finals (n = 6), only the semi-finals and finals (n = 3) or exclusively the finals (n = 2). Additionally, several studies were conducted in more controlled settings (e.g., 'simulated competition') in which participants were tasked with swimming a time trial without an opponent (n = 6). One article explored data collected during real and simulated competition scenarios entailing one or two opponents. No significant difference was found between pacing profiles in simulated competitions (with an opponent) and in real competitions ($p>0.22$). However, in real competitions, absolute velocity was higher during all sections of the race ($p<0.001$) (34). Three of the studies conducted in a simulated competition examined the effect of an imposed manipulation of swimmers' pacing behaviours on their performance outcomes. Only one study of swimmers in real competition related observed pacing profiles to total race time.

A total of 12 of the 16 reviewed studies showed a higher velocity in the starting phase of the race. This phenomenon was observed for all four distances (100 m: n = 3, 200 m: n = 7, 400 m: n = 8, 800 m: n = 3) and all stroke types. Pacing profiles for 100 m and 200 m races showed a high velocity during the first 50 m (35-39). For the 400 m profile, a high velocity either occurred during the first 50 m (40, 41) or 100 m (37). In the 800 m freestyle races, a high velocity was reported for the initial 100 m freestyle (34, 36). The high velocity during the starting phase was reported in several studies that excluded the first 15 m of the race in the velocity measurements (33, 35). Correspondingly, it was reported in studies in which swimmers were instructed to start from the water (42, 43). Thus, it can be stated that the high velocity during the starting phase occurs independently of the dive start.

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Table 1. A quality assessment of the included articles in alphabetical order applying the guidelines developed by Letts et al.

Assessment questions →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
1. Dormehl and Osborough (2015)	1	1	1	0	0	1	0	0	1	1	1	1	0	0	8
2. Figueiredo, Zamparo, Sousa, Vilas-Boas, & Fernandes (2011)	1	1	1	0	0	1	0	0	1	1	1	1	0	0	8
3. Lipinska, Allen, and Hopkins (2016)	1	1	1	0	0	1[a]	0	0	1	1	0	1	1	0	8
4. Mauger, Neuloh, & Castle (2012)	1	1	1	0	0	1[b]	0	0	1	1	1	1	1	1	10
5. Mytton *et al.* (2015)	1	1	1	0	1	1[a]	0	0	1	1	1	1	0	1	10
6. Nikolaidis and Knechtle (2017)	1	1	1	0	0	1[a]	0	0	1	1	1	1	1	1	10
7. Robertson, Pyne, Hopkins, & Anson (2009)	1	1	1	0	0	1[a]	0	0	0	1	1	1	1	1	9
8. Saavedra, Escalante, Garcia-Hermoso, Arellano, & Navarro (2012)	1	1	1	0	0	1[a]	1	1	1	1	1	1	0	0	10

Table 1. A(Continued)

Assessment questions →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
9. Schnitzler, Seifert, & Chollet (2009)	1	1	1	0	0	1	0	0	1	1	1	1	1	0	9
10. Skorski, Faude, Abbiss, *et al.* (2014)	1	1	1	0	0	1	1	1	1	1	1	1	1	1	12
11. Skorski, Faude, Caviezel, & Meyer (2014)	1	1	1	0	0	1[a]	1	1	1	1	1	1	1	1	12
12. Skorski, Faude, Rausch, & Meyer *et al.* (2013)	1	1	1	0	0	1	0	0	1	1	1	1	1	1	10
13. Taylor, Santi, & Mellalieu (2016)	1	1	1	0	0	1[b]	0	0	1	1	1	1	0	1	9
14. Thompson, MacLaren, Lees, &Atkinson (2003)	1	1	1	0	0	1	0	0	1	1	1	1	0	0	8
15. Thompson, MacLaren, Lees, & Atkinson (2004)	1	1	1	0	0	1	0	0	1	1	1	1	0	0	8
16. Veiga and Roig (2016)	1	1	1	0	0	1[b]	0	0	1	1	1	1	0	1	9

a = records were in the public domain. b = no informed consent but there was ethical approval.
Included questions (scored either 0 or 1): 1.Was the aim of the study and purpose stated clearly? 2.Was relevant background literature reviewed? 3.Was the study design appropriate for the research question? 4.Were the participants relevant to the research question and was their selection well-reasoned? 5.Was the sample size justified? 6.Was informed consent obtained? 7.Were the outcome measures reliable? 8.Were the outcome measures valid? 9.Were results reported in terms of statistical significance? 10.Were the data collection methods appropriate for the research design? 11.Did a meaningful picture of the phenomenon under study emerge? 12.Were conclusions appropriate given the study findings? 13.Are there any implications for future research given the results of the study? 14.Were limitations of the study acknowledged and described by the authors?

3.2. Race distance

Different features in the pacing profile were observed depending on the race distance. In all three studies of 100 m races, it was observed that the pacing profiles of swimmers, both elite and competitive, were positive (35-37). The pacing profiles of swimmers in races over 200 m were analysed in 10 studies. In studies that focused on 200 m competitions, both real and simulated, in 25 m and 50 m pools, elite swimmers showed a high-velocity start followed by a large decrease in velocity during the second lap, a small decrease in velocity during the third lap and a constant velocity up to the end of the race (38, 39, 42). In one study that investigated competitive swimmers performing 200 m freestyle, the velocity increased in the final lap (2.1%) (36). The pacing profiles of swimmers in 400 m races were examined in a total of 10 studies. Elite swimmers performing freestyle and medley in real competitions displayed parabolic pacing profiles, with significantly higher velocities during the first and last sections than in other sections of the race ($p<0.001$) (37, 38, 40, 44). Swimmers with parabolic pacing profiles performed significantly better than the swimmers who displayed one of the other pacing profiles. This finding applied to both males ($p<0.001$) and females ($p<0.001$) (45). Two studies found that during 400 m races in real competitions, the most common pacing profiles among elite swimmers performing freestyle were the fast-start-even and parabolic profiles (33, 45). Three studies examined the pacing profiles of swimmers performing in 800 m races. A first section at a fast pace, followed by a gradual decrease in the normalised velocity during the 200–700 m and increased normalised velocity during the final 100 m was observed among adolescent sub-elite swimmers (34). A study of in elite female swimmers performing freestyle during real competition confirmed these characteristics, reporting a gradual decrease in velocity throughout the race, with the slowest lap time in the eleventh lap (500–550 m) (46). Among competitive freestyle swimmers, split times increased during the 100–200 m (8.8%) and 200–600m sections (0.2% – 1.0%) and decreased during the 600–700m (0.3%) and 700–800m sections (3.4%) ($p<0.001$) (36).

3.3. Stroke types

In addition to the duration of the race, certain deviations in pacing behaviour were caused by the different stroke types. Elite swimmers in 200 m freestyle, butterfly and backstroke races tended to display a fast-even profile, with a fast first 50 m section for all three stroke types ($p<0.001$ for all other sections). Additionally, in the freestyle and backstroke events, the second 50 m lap was also faster than the third and fourth laps ($p<0.001$) (38). The pacing profile of swimmers performing breaststroke was characterised by a high velocity during the first 50 m lap and a gradual decrease in normalised velocity with every 50 m lap ($p<0.001$) (38, 47, 48). Furthermore, more variability was observed in the pacing profiles of swimmers performing breaststroke during the entire race (38). Individual medley events were examined in two studies. Elite swimmers participating in 200 m and 400 m individual medley real competitions demonstrated a parabolic pacing profile in which they performed butterfly strokes for the smallest percentage of the total race time, followed by freestyle, backstroke and breaststroke (37, 44).

3.4. Biomechanics and metabolic systems

The metabolic systems used in swimming competitions were described in three studies (42, 47, 48). One study that investigated a 200 m freestyle race reported that the percentage of the total metabolic power output covered by the aerobic energy system increased over the duration of the race, from 45% during the first lap to 83% in the third lap, with a drop to 66% during the final lap. Conversely, the coverage of the anaerobic system decreased over the duration of the race, from 55% during the first lap to 17% during the third lap, with a small increase to 24% during the final lap (42). It was reported that as the race time increased, the blood lactate peak value correspondingly increased, which was linked to increased fatigue throughout the race (42, 47, 48). In all four studies that measured biomechanical characteristics in adult swimmers, the SL decreased throughout the race. One study on sub-elite swimmers performing freestyle in a 400 m race showed a drop in SL after the first 50 m and during the last 100 m, whereas the SR remained unchanged during the race (43). However, the other three studies reported a decrease in SL accompanied by an increase in SR (42, 47, 48). Additionally, swimming performance was subdivided into surface and underwater swimming within one study, who reported that although the velocity in surface swimming decreased by 6–8% over a 200 m freestyle race, the underwater velocity remained constant (39).

3.5. Medallists vs non-medallists

The pacing behaviour of swimmers in the finals of elite competitions was compared in three studies. Two studies found that the pacing behaviour expressed in lap times, and therefore representing absolute velocity, was similar for swimmers ranked in first to sixteenth (37) or first to eighth (40) place. However, a comparison of the normalised velocity showed that medallists had a relatively lower normalised velocity in both the first 100 m (102.2 ± 1.2% vs 103.1 ± 1.1%, $p<0.05$) and the second 100 m (97.7 ± 0.8% vs 98.2 ± 0.6%, $p<0.001$) compared to swimmers ranked fourth to eighth place. In the third 100 m, there was no difference between medallists and non-medallists (98.5 ± 1.0% vs 98.4 ± 0.6%, $p=0.63$). In the final 100 m, medallists had a higher normalised velocity compared to non-medallists (101.8 ± 1.7% vs 100.5 ± 1.2%, $p<0.05$) (40). Among elite swimmers performing a 200 m medley, it was observed that medallists had a higher absolute velocity than non-medallists (fourth to sixteenth place) throughout the race. However, medallists invested more time in butterfly and freestyle strokes ($p<0.001$) and less in backstroke ($p<0.001$) and breaststroke ($p<0.05$) than swimmers ranked in ninth to sixteenth place (44). In the 400 m medley, medallists invested more time in butterfly strokes ($p<0.001$) and less in backstroke ($p<0.05$) and breaststroke ($p<0.05$) compared with swimmers ranked in ninth to sixteenth place (44).

3.6. Pacing in adolescent swimmers

Three studies focused on the pacing behaviours of adolescent swimmers. One study found no difference in the pacing profiles of younger and older adolescent swimmers (group 1: aged 14.4 ± 0.7 years; group 2: aged 17.0 ± .8 years) performing in 200 m freestyle real competitions (35). The pacing profile observed in this study corresponds to the profile displayed by elite swimmers competing in the same event (38, 39). A comparison of adolescent sub-elite swimmers (aged 16.9 ± 2.1 years) with elite adult swimmers (aged 22.8 ± 2.9 years) participating in 200 m and 400 m freestyle races revealed that the variability of the pacing profiles of both adult and adolescent swimmers was low throughout the race. However, in the last quarter of the race, the variability was higher among adolescent swimmers than among adult swimmers (34, 38). Furthermore, the findings of a study of sub-elite adolescent swimmers (males: 19.2 ± 2.0 years, females: 16.2 ± 1.8 years) participating in a 400 m freestyle race revealed better performances of seven out of 15 swimmers in a trial with an imposed manipulated pacing profile compared with performances in trials entailing a self-regulated pace (41).

4. Discussion

Pacing behaviour in swimming is characterised by a high-velocity start and is influenced by racing distance. The study findings indicate that when the racing distance increases, the swimmers' pacing profiles change from being positive (100 m races) to being more parabolic (400 m and 800 m races). In elite finals, the best-performing swimmers demonstrated a higher absolute velocity throughout the race (37, 40, 44). However, the pacing profiles of the top three performers differed from those of the other finalists (40, 44). Namely, medallists showed a lower normalised velocity during the first half of the race and a higher normalised velocity during the last portion of the race (40). Notably, all of these characteristics are similar to those reported in studies of time-trial competitions (3, 4, 9, 11, 18, 30, 49). Swimming is a head-to-head competition in which the winner is the athlete who covers the given race distance first, regardless of the time taken. Nevertheless, distinct differences between athletes' pacing behaviours were observed in 400 m swimming and 1,500 m running competitions, although both sports entail head-to-head competitions of similar duration (40). Additionally, the characteristics of the pacing profile in swimming are similar to those of athletes in time-trial sports. This similarity is most likely caused by the separation of competitors through the use of lanes, thereby preventing tactical behaviour as seen in classic head-to-head sports (e.g., drafting behind an opponent), which enables a swimmer to be more independent of other competitors. This explanation is supported by the fact that studies on rowing, another head-to-head sport in which competitors are separated by lanes, have reported pacing behaviour which resembles pacing profiles of time-trial sports (50, 51).

The different stroke types are a distinctive feature of pool swimming. There appear to be marked differences in swimmers' pacing profiles associated with different stroke types (38, 39), indicating that stroke type affects pacing behaviour. Most notably, the pacing profiles of swimmers performing breaststroke, in contrast to other strokes, were characteristically positive (38, 47, 48). In addition, in races, the variability of pacing profiles was higher for swimmers performing the breaststroke than that for swimmers performing other strokes (38). A possible explanation could be found in the finding that the breaststroke technique features a large intra-cyclic variation of swimming velocity (25). Higher intra-cyclic variations in velocity prompt more mechanical work by swimmers and consequently induce greater energy expenditure (25). This increased energy expenditure could be the reason for the decrease in swimming velocity in the last lap as well as the increased variation throughout the race.

A comparison of the contribution of energy systems in the course of a swimming race to a track cycling task of similar duration (141.3 ± 4.5 s for swimming vs 133.8 ± 6.6 s for cycling) reveals a clear difference between the two sports (42, 49). The contribution of the anaerobic system during swimming is around 56% after the first 50 m, thereafter decreasing with a corresponding increase in the aerobic contribution during the race, which reaches a high point of 83% during the third lap (42). In track cycling, the contribution of the anaerobic energetic system is around 75% during the first 30 seconds (49), which is comparable to the first 50 m in swimming. The aerobic system only takes over as the predominant energy system at the 100 s mark (49). This difference in the contributions of the two energetic systems could be attributed to low efficiency in swimming caused by the increased energy loss to the environment. This low efficiency could place a greater demand on the anaerobic system to maintain velocity. Consequently, the accumulation of blood lactate, and associated symptoms of fatigue, occur faster during a swimming event than in a track cycling event of the same duration. This relatively fast onset of blood lactate accumulation is also reflected in biomechanical characteristics. As blood lactate level increases over the duration of the race, SL tends to decrease (42, 43, 47, 48). However, as noted in previous studies, it is essential to minimise large variations in velocity throughout the race (12, 22). Therefore, to maintain velocity, swimmers must increase SR during the race. Notably, a high SR is associated with a higher level of drag than a high SL and a low SR. Additionally, it appears that whereas elite swimmers maintain underwater velocity during the race, surface velocity decreases (39). This finding accords with the previously mentioned goals of minimising drag and maintaining velocity throughout the race. As for the underwater phase of the lap, drag is minimised through the streamlined body position. Consequently, the highest velocity is achieved during this phase of the race. A recent study that examined behavioural differences in pacing between and within the laps of elite swimmers confirmed the occurrence of changes in biomechanical characteristics resulting from increasing fatigue as well as the maintenance of constant underwater velocity throughout the race (52). This study concluded that swimmers' pacing profiles within the first lap evidenced a decreasing velocity because of the loss of velocity following the dive. The dive is the fastest part of the race because of the initial acceleration as well as the airborne locomotion, compared with the rest of the race in which locomotion occurs in water (24). Additionally, the swimmers' pacing behaviour within the second and third laps is characterised by a decrease in velocity at the end of the lap as they prepare to turn and by an increase of velocity during the underwater phase attributed to decreased drag.

Because of the scarce literature on adolescent swimmers' pacing behaviour (n = 3), it is difficult to provide a detailed description of the pacing behaviour of adolescent swimmers. No direct differences in the pacing profiles of adolescent and adult swimmers were found. However, the pacing profiles of adolescent swimmers were evidently more variable, and these swimmers demonstrated difficulty in self-selecting the most beneficial pacing profile. This could indicate that adolescent swimmers struggle to regulate their energy distribution in the most efficient manner. This inability to pace efficiently was also found in a study of adolescent swimmers (15 ± 1.5 years) performing a swimming incremental step test (53). Adolescent swimmers' incompetence in stabilising their pacing behaviour may be related to the finding that pacing skills are contingent on prior experience and the level of (meta-) cognitive functioning, requiring time to fully develop (4, 13, 14, 54). A recently proposed model for developing athletes' pacing skills emphasises the importance of both the experiential and self-regulatory aspects of skill learning (14). Self-regulation has proven essential for an efficient training regime (55). By supporting the multiple cyclical facets of self-regulation learning (reflection, planning, performance and evaluation), coaches can facilitate the development of young athletes' pacing behaviour. The importance of this development was recently highlighted in a longitudinal study of adolescent speed skaters (18). The findings indicated that adolescent athletes whose pacing profiles resemble those of elite performers in an earlier stage of their development went on to achieve higher performance levels in their later careers compared to their peers at the adolescent level (18). As swimmers' pacing behaviours resemble those of athletes in time-trial sports like speed skating, it is plausible that swimmers also demonstrate a similar relation between the development of their pacing behaviour and their performance in later stages of their careers. Further research on the development of pacing behaviour in swimming is required to address this question.

5. Conclusion

The present study is the first systematic investigation of the body of literature on pacing behaviour in pool swimming. Although swimming is a head-to-head sport, the pacing behaviour of swimmers in this type of competition is similar to that of athletes in time-trial sports. A positive profile is evident in shorter races (100 m), whereas a more parabolic profile is prevalent in the longer races (400 and 800 m). Additionally, elite medallists demonstrate more conservative pacing behaviour, characterised by a lower normalised velocity in the initial phase of the race and a higher normalised velocity in the final phase. Given the unique characteristics of the breaststroke event, the swimmers' pacing profile markedly deviates from those of other strokes, being more positive. Blood lactate accumulates throughout the race, prompting a decrease in SL and a consequent increase in SR during the course of the race to minimise variations in velocity. The pacing profiles of adolescent swimmers are more variable than those of elite swimmers, and young swimmers tend to have difficulty effectively regulating their energy distribution to achieve the highest performance outcome. The relationship between pacing behaviour and performance development in swimmers needs to be further explored in future studies.

6. Declaration of interests

The authors report no potential conflicts of interest that are related to the content of this review.

Table 2. An overview of the reviewed studies on pacing behaviour in pool swimming ordered by race distance (n =16).

Study	Race distance	Gender and number of participants	Age (years)	Performance level	Stroke type	Competition type (stage of competition)
Dormehl & Osborough (2015)	100m[1], 200m[1]	Male (n=56), Female (n=56)	Group 1: 14.4±0.7 Group2: 17.0±0.9	Competitive	Freestyle	Real competition (heats, semi-finals and finals)
Robertson, Pyne, Hopkins, & Anson (2009)	100m[2], 200m[2], 400m[2]	Male (n=1530), Female (n=1527)	n/a	Elite	100m, 200m: Freestyle, breaststroke, butterfly, backstroke. medley. 400m: Freestyle, medley	Real competition (semi-finals and finals)
Nikolaidis & Knechtle (2017)	100m[2], 200m[2], 400m[2], 800m[2]	Males (n=2260), Females (n=2221)	25-94	Competitive	Freestyle	Real competition (heats, semi-finals and finals)

Methods	Statistical analyses	Pacing profile	Main results	Main findings
Races collected at international schools swimming championships[1]. Race split up in quarters. For 200m: laps 1, 3 and 5 for quarter 1, 2 and 3. Quarter 4 is combination of laps 7 and 8 Measurements: -Race time -Velocity per quarter. (Velocity of first quarter was measured between 15m and 20m to account for dive. Remainders over a 10m midsection of the pool)	-Repeated measurements ANOVA's -Post-Hoc (Bonferroni)	-Positive	-No difference in pacing profile between groups 100m: -Velocity decreased for each quarter. 200m: -Velocity decreased for each quarter except for the last quarter in which it did not differ from the third quarter.	-No difference in pacing profile between two age groups 100m: -Decrease of velocity throughout the race 200m: -The velocity decreased gradually decrease until the third quarter of the race. It remained unchanged in the final quarter.
Races collected during OG, WC, EC and CG over a 7 year period. Measurements: -Total race time -Split times (50m or 100m) -Placing for top 16 finishers	Lap times of finalists and semi-finalists, the mean lap times for all the swimmers (placed 1–16) were plotted between-athletes and within-athletes.	100m: Positive 200m: Fast-start-even. 400m: Parabolic	-Winners maintained a lead through each of the intermediate laps. -Pacing profile: faster first lap (~1-3s) , followed by evenly paced middle laps and an evenly paced or slightly faster (~1s) final lap. -The most successful(top 3 of 16) swimmers were faster in all the laps.	-Similar pacing profile for all 16 swimmers. -Pacing profile: 100m: positive. 200m and 400m: a fast first lap followed by evenly paced middle laps and an evenly of faster final lap.
Races were collected during the Masters championships 2014. Measurements -50m split times (200m, 400m) -100m split times (800m) -Total race time	-Mixed-design factorial ANOVA -Post-Hoc (Bonferroni) test. Effect size eta squared ($\eta2$): small ($0.010 < \eta2 \leq 0.059$), moderate ($0.059 < \eta2 \leq 0.138$) and large ($\eta2 > 0.138$).	-Parabolic -Positive	100m: Velocity 1^{st} lap > 2^{th} lap (+11.6%) 200m: Velocity: 1^{st} lap > 2^{th} lap (+11.6%) > 3^{th} lap (+3.8%) < 4^{th} lap (–2.1%) ($P < 0.001$, $\eta2 = 0.847$), - Larger changes in older age groups than in the younger groups, both in women ($P < 0.001$, $\eta2 = 0.195$)and men ($P < 0.001$, $\eta2 = 0.200$). 400m: -Swimming time: 50–100 m (+11.1%), 101–150 m (+2.9%), 151–200 m (+1.2%), 201–250m (unchanged), 251–300 m (+0.5%), 301–350 m (–0.6%), 351–400 m (–4.5%) ($P < 0.001$, $\eta2 = 0.856$). -Larger changes in older age groups than in the younger groups, both in women ($P < 0.001$, $\eta2 = 0.176$) and men ($P < 0.001$, $\eta2 = 0.131$). 800m: -Swimming time: 100–200 m (+8.8%), 201–300 m (+1.0%), 301–400 m (+0.5%), 401–500 m (+0.2%), 501–600 m (+0.2%), 601–700 m (–0.3%) 701–800 m (–3.4%) ($P < 0.001$, $\eta2 = 0.842$). - Larger changes in older age groups than in the younger groups in men ($P < 0.001$, $\eta2 = 0.105$).	-In 100m freestyle a positive pacing profile is found. -There is a general pacing profile in the 200m, 400m and 800m freestyle in master swimmers. A large increase in swimming time during the second lap, a decrease or a constant during the other laps and increase in swimming time during the last lap(s). -There are larger changes in swimming time by lap in the older age groups than in the younger groups.

Table 2. (Continued)

Study	Race distance	Gender and number of participants	Age (years)	Performance level	Stroke type	Competition type (stage of competition)
Thompson, MacLaren, Lees & Atkinson (2003)	200m. 175m	Male (n=9)	21.2±2.6	Sub-Elite	Breaststroke	Simulated competition (without opponent)
Thompson, MacLaren, Lees, & Atkinson (2004)	200m	Male (n=9)	22.5±4.5	Competitive	Breaststroke	Simulated competition (without opponent)
Figueiredo, Zamparo, Sousa, Vilas-Boas, & Fernandes (2011)	200m[1]	Male (n=10)	21.6±2.4	Elite	Freestyle	Simulated competition (without opponent)

Methods	Statistical analyses	Pacing profile	Main results	Main findings
200m test trial 3 paced 175m trials. Measurements: -50m split times -HR -RPE -La (post-trial)	-Dependent t-tests -one-way ANOVA -Factorial ANOVA -Post hoc (Tukey's HSD)	-Even -Positive -Negative	-Difference in split times (p<0.01) -No difference in finishing times (p<0.05). -The 200 test trial: positively paced (split time: 72.2±8.6s; finish time: 148.0±13.2s) -RPE: even < positive, 200m trial trial (p < 0.05). -HR: negative trial < others (p < 0.05)	-The pacing strategy of choice was positive pacing. -Even pacing shows reduced blood lactate & RPE compared to positive paced. -Performance: even = positive.
200m test trial 3 paced 200m trials: -98% of 200m time -100% of 200m time -102% of 200m time Measurements: -50m split times -HR -Respiratory exchange ratio (RER) (post-trial) -La (post-trial)	-Dependent t-tests a -One-way ANOVA -Factorial ANOVA -Post-hoc (Tukey's HSD)	-Positive	-Finishing times: different (F=28.37, p<0.01). 102% > 100% (0.8%, p<0.05). - 102% was positively paced (t=4.88, p<0.006). -RER and blood lactate 102% > 100% & 98% (p<0.05) -PRE: 102% > 98% (p<0.05) -HR: at 100m 102% > 98% (F=4.00, p<0.03). No difference at 200m.	-Positive pacing profile in 102% trial. -102% trial was completed only 0.8% faster to even-paced 100% trial (non-significant difference).
50m, 100m, 150m and 200m trial at 200m velocity. No dive, no underwater phase. Measurements: -50m split times. -Velocity during every 50m. -VO_2 -La (post-trial) -Aerobic, anaerobic (lactate and alactic) -Total energy expenditure	-One-way repeated measures ANOVA -Post-Hoc (Bonferroni -Cohen's f; small (0 ≤ f ≤ 0.10), medium (0.10 < f ≤ 0.25); and large effect size (f > 0.25).	Fast-start-even.	-Velocity: first lap > other laps ($F_{3,27}$=24.72, p<0.01, f=1.04) -Split time: first lap < other laps ($F_{3,27}$=30.753, p<0.001, f=1.23) -Aerobic contribution: stable the last 3 laps, lower in 1^{st} lap ($F_{3,27}$=110.515, p<0.001, f=5.69). -Anaerobic anlactic contribution: 1^{st} lap > other laps ($F_{3,27}$=925.91, <0.01, f=5.69) -Anaerobic lactate contribution: 1^{st} lap > other laps ($F_{3,27}$=66.131, p<0.001, f=1.73) -Total energy expenditure: 1^{st} & 4^{th} lap > other laps ($F_{3,27}$=19.578, p<0.001, f=0.59) -Total energy expenditure: 2^{th} lap > 3^{th} lap ($F_{3,27}$=29.137, p<0.001, f=0.80).	-Aerobic contribution increases over the race whiles anaerobic alactric contribution decreases. -Anaerobic lactate contribution increased in the final lap

Table 2. (Continued)

Study	Race distance	Gender and number of participants	Age (years)	Performance level	Stroke type	Competition type (stage of competition)
Veiga & Roig (2016)	200m[2]	Males (n=64), Females (n=64)	n/a.	Elite	Butterfly, backstroke, breaststroke, freestyle.	Real competition (semi-finals and finals)
Saavedra, Escalante, Garcia-Hermoso, Arellano, & Navarro (2012)	200m[2], 400m[2]	Male (n=821), Female (n=822)	n/a	Elite	Medley	Real competition (semi-finals and finals)

Methods	Statistical analyses	Pacing profile	Main results	Main findings
Races collected during the FINA WC 2013. Measurements: -average underwater velocity -average free swimming velocity -average lap velocity	-Repeated-measurement ANOVA -Univariate analyses using Wilks' methods.	-Positive pacing	-Free swimming velocity: 1st lap > 2th lap (−0.08 m·s^{-1}, −0.07 to −0.09 m·s^{-1}, P =0.001) 2th lap > 3th lap > 4th lap (both −0.02 m·s^{-1}, −0.01 to −0.03 m·s^{-1}, P = 0.001). -Underwater velocity : 1st turn > 2th turn (−0.03 m·s^{-1}, −0.01 to −0. m·s^{-1}, P = 0.005), 2th = 3th turn (0.01 m·s^{-1}, −0.01 to 0.03 m·s^{-1}, P = 0.55). -Average velocity: 1stlap > 2th lap (−0.15 m·s^{-1}, −0.15 to −0.16 m·s^{-1}, P = 0.001) 2th lap >3th lap (−0.03 m·s^{-1}, −0.02 to −0.03 m·s^{-1}, P = 0.001). 3th lap = 4th lap (−0.01 m·s^{-1}, −0.02 to 0.00 m·s^{-1}, P = 0.29).	-The free swimming velocity decreases across the 200 m race laps, the velocity in the underwater swimming is not affected by the race progress and is faster than free swimming. -Average velocity decreases after first lap, and slightly after second lap, is maintained during third and fourth lap.
Races were collected during OG. WC, EC, CG, PPC, U.S. Olympic team trials, Australian Olympic team trial in 2000-2011. Measurements: -Total race time -50m split times -percentage of total time spend in a lap.	-A two-way ANOVA sex*classification -Post-Hoc (Bonferroni)	-Parabolic	200m: -The percentage of time spend per stroke: Butterfly men (22.59±0.42), women (22.65±0.42) < freestyle men (23.20±0.42), women (22.90±0.46) < backstroke men (25.62±0.53), women (25.52±0.52) < breaststroke men (28.59±0.60), women (28.93±0.65) -The best swimmers: greater percentage in butterfly and freestyle (p<0.001) and less in backstroke (p<0.001) and breaststroke (p<0.021) compared to the lowest classified swimmers. 400m: -The best swimmers: greater percentage in butterfly and backstroke (p<0.001) and less in backstroke (p<0.018) and breaststroke (p<0.024) compared to the lowest classified swimmers.	-The smallest percentage of time was spend in butterfly followed by freestyle, backstroke and breaststroke. -Best swimmers spend more time in butterfly and freestyle and less in breaststroke and (in 400m) backstroke

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Table 2. (Continued)

Study	Race distance	Gender and number of participants	Age (years)	Performance level	Stroke type	Competition type (stage of competition)
Skorski, Faude, Caviezel, & Meyer (2014)	200m^2, 400m^2	Male (n=158)	22.8±2.9	Elite	200m: freestyle, butterfly, backstroke, breaststroke. 400m: freestyle	Real competition (heats, semi-finals and finals)
Skorski. Faude, Rauch, & Meyer. (2013)	200m^2, 400m^2, 800m^2	Male (n=9), Female (n=7)	16.9±2.1	Sub-Elite	Freestyle	Simulated competition (with opponents) & Real competition (heats, semi-finals and finals)

Methods	Statistical analyses	Pacing profile	Main results	Main findings
Races of top 50 swimmers collected during 22 national and international events as well as the races of the finals (1th-16th place) of the PPC and EC. Measurements: -Overall race times -50m split times -Normalized velocity	-Repeated measures ANOVA (factor 1, competition; factor 2, section of the race) -Post-Hoc (Scheffé).	-Fast-start-even -Positive -Parabolic	-Average performance improvement from heat to final was 1.2% (CL 0.6-2.2%). -Pacing pattern: Fast-start-even pattern in 200m freestyle, butterfly and backstroke. Velocity in 1th lap > others.(P<.001) and 2th lap > 3th and 4th in freestyle and backstroke (P<.001). Positive profile in breaststroke (P<.001). Parabolic profile in 400m freestyle. Velocity in 1st lap > others (P<.001). Last lap > others (P<.001). -Heat paced similar to finals (interaction: all P>.06). 50m split times were faster finals (P<.02). -Normalized pacing pattern was not significantly different between competitions 1 and 2 (P>.18). -CV's for intra-individual differences in split times between heats and finals were small for all 200m races (<2.2%; CL 0.6-3.2%). In 400m freestyle, values increased in the course of the race up to 2.9% (CL 2.2-4.5%) in the last section.	-Pacing pattern is consistent between competitions in elite swimmers. -Elite swimmers showed a fast-start-even (freestyle, butterfly, backstroke) and positive pacing (breaststroke) during 200m and parabolic-shaped pattern during 400m freestyle. -Swimmers choose the same pacing pattern during heats and finals but with a lower average velocity during heats.
-Six simulated competitions (SC: 2x 200m, 2x 400m and 2x 800m. -Real competition races (RC) Measurements: -50m splits times (200m) and 100m splits (400m, 800m). -Peak blood lactate values (post-trial) -HR (post trial)	-2-way repeated measures ANOVA test*section of test -Cohen's d -Within-subject-variation by means of the SEM and log-transformed CV.	-Fast-start-even	-Fast-start profile during SC (p<0.002) and RC (p<0.001). -CV for test-retest small for first 3 sections (CV < 2.0%, for first 6 sections of 800m) and increased towards the end. -Pacing pattern SC = RC (p>0.22). -Pacing pattern for absolute velocities SC = RC (p>0.10), all section times faster during RC (p<0.001). -SEM in split times between SC and RC were small in the middle of the race during 800m (200m-600m) and 400m (200m-300m) (SEM <1.6s). The first section higher SEM in both distances (>1.8s). The last section of the during the 400m (300m-400m) and the 2 last sections during the 800m (600m-800m) showed higher SEM (>1.8s).	-Pacing profile (fast-start-even) is consistent during the first three quarters of the race (CV <2%). The absolute variability in split times in the last quarters was higher (CV= 2.2-2.9%). -Athletes show similar a pacing pattern in SC and RC -Race times faster in RC during all sections of the race.

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Table 2. (Continued)

Study	Race distance	Gender and number of participants	Age (years)	Performance level	Stroke type	Competition type (stage of competition)
Mauger, Neuloh, & Castle. (2012)	400m[2]	Male (n=147), Female (n=117)	n/a	Elite	Freestyle	Real competition (finals)
Taylor, Santi, & Mellalieu (2016)	400m[2]	Male (n=489), Female (n=312)	n/a	Elite	Freestyle	Real competition (heats, semi-finals and finals)

Methods	Statistical analyses	Pacing profile	Main results	Main findings
Races collected at the EC, WC, British and Australian national championship and International Invitational Meets, CG and OG in period 2003-2010. Measurements: -Total race time -50m split times -Mean velocity of every lap (excluding first 10m after the start and first and last 5m of every lane). Pacing profiles were determined by an algorithm based on normalized velocity.	Data were analyzed using a three-way ANOVA (pacing strategy _ sex _ swimming suit) in an unrelated design (p=0.05).	-Parabolic -Fast-start-even -Positive -Negative -Even	-Fast-start-even and parabolic pacing profiles used the most, with parabolic profiles preferred by men. -Fast-start-even pacing profile performed at 96.08±2.12% of the (228.4±4.66s). -Parabolic pacing profile performed at 96.04±2.2% of the WR (228.7±4.84s) -Positive pacing profile performed at 95.4±2.19% of the (230.15±4.82s) -1.7s performance difference between fast-start-even and positive pacing ($F_{2,228}$ = 1.00, P>0.05).	-Fast-start-even and parabolic pacing profiles used more frequently -Profile preference regardless of sex -Functional difference between profiles during competition appears to be minimal. -No specific single profile had significant influence on performance.
Races collected at the WC, EC, OG between 2006 and 2012. Measurements: -50m split times -Normalized 50m split time	-*k*-means cluster analysis -One-way ANOVA -Cohen's d.	-Fast-start -Positive -Parabolic	-In males mean race time in parabolic pacing (mean race time = 230.57 s, 95% CL = 229.51–231.63) < fast-start-even pacing (mean race time = 235.91 s, 95% CL = 234.81–237.01),and positive (mean race time = 252.66 s, 95% CL = 249.26–256.06) -In females mean race time in parabolic pacing profile (mean race time = 249.59 s, 95% CL = 248.47–250.71) < fast-start-even (mean race time = 253.94 s, 95% CL = 252.87–255.01), positive (mean race time = 262.76 s, 95% CL = 260.05–265.47) -Fast-start-even and parabolic pacing profiles were most frequently observed. 220 and 182 for males (n=498) and 105 and 135 for females (n=312) respectively.	-In elite swimmer the parabolic pacing profile resulted in the lowest race times, followed by the fast-start-even profile. - Parabolic and fast-start-even profiles were most frequently chosen by the elite athletes.

Table 2. (Continued)

Study	Race distance	Gender and number of participants	Age (years)	Performance level	Stroke type	Competition type (stage of competition)
Mytton et al. (2015)	400m[2]	Male (n=48)	n/a	Elite .	Freestyle	Real competition (finals)
Skorski et al. (2014)	400m[2]	Male (n=10), female (n=5)	Male: 19.2±2.0 Female: 16.2±1.8	Sub-Elite	Freestyle	Simulated competition (without opponent)
Schnitzler, Seifert, & Chollet (2009)	400m[1]	Male (n=6), Female (n=6).	18.2±2.2	Sub-Elite	Freestyle	Simulated competition (without opponent)

Methods	Statistical analyses	Pacing profile	Main results	Main findings
Races collected at the EC 2006, 2010, 2012. WC 2007, 2010 and CG 2006. Measurements: -50m split times -Velocity per lap -Normalized velocity	-Mann Whitney test -Kruskal-Wallis test -Cohens *d* effect size: trivial (<0.2), small (0.2-0.6), moderate (0.6-1.2) and large (1.2-2.0).	-Fast-start-even -Parabolic	-Medallists: larger variation in velocity compared to non-medallists -Lap one: normalized velocity medallists < non-medallists (102.2±1.2%, 103.1±1.1%, p=0.03, *d* = 0.75). Gold medallists = others -Lap two: normalized velocity medallists < non-medallists (97.7±0.8%, 98.2±0.6%, p<0.001, *d* = 0.78). -Lap three: Normalized velocity medallists = non-medallists (98.5±1.0%, 98.4±0.6%, p=0.63). Gold medallist > 4th-8th place (p=0.04 to 0.002). -Lap four: Normalized velocity medallists > medallists (101.8±1.7%, 100.5±1.2%, p≤0.01, *d* = 0.93 moderate).	-Medallist, compared to non-medallists, swim a relatively slower first and second 100m. In the third 100m there is no difference and the final 100m is faster.
Self-paced trial (PP_{SS}), trial with first 100m paced 3% slower compared to PP_{ss} (PP_{SLOW}), trial with first 100m paced 3% faster compared to PP_{ss} (PP_{FAST}). Controlled for the dive start. Measurements: -Total racing time -50m split times -La (post-trial) -Normalized velocity	-One-way repeated-measures ANOVA -Two-way ANOVA SR and normalized velocity between trials (with and without start dive). -Post-Hoc (Scheffé) -Cohen d effect (0.2, 0.6, 1.2, 2.0, and 4.0 for trivial, small, moderate, large, very large, and extremely large, respectively)	-Parabolic	-Overall performance compared to PP_{SS}: < PP_{FAST} (278.5±16.4s) (P=.05). < PP_{SLOW} (277.5±16.1s) (P=.20). - 7 out of 15 subjects faster time in a manipulated race (3 in PP_{FAST}, 4 in PP_{SLOW}) -Pacing was different between conditions in the first 100m (P<0.001), not in the rest of the trial (P=0.45). -Including the dive start: in all conditions the first 50m were faster compared to the remaining sections of the trial (P<0.001). -Blood lactate (P=.33) and HR (P=.47) were not different between conditions.	-Manipulation during the initial 100m of a 400m freestyle event reduces overall performance (more than 2.5s) -7 out of 15 participant recorded their fastest time during a manipulated trial.
100m, 200m, 300m and 400m at 400m velocity. No dive start. Measurements: -HR -La (post-trial) -Mean speed every 50m (V50) -Workload (TWL). By the NASA-TLX questionnaire.	-Three-way ANOVA (fixed factors: swim, gender; random factor: subject) -Three-way ANOVA (fixed factors: swim distance, gender; random factor: subject) -Post-Hoc (Tukey HSD) -CV -One-way ANOVA	-Even	-HR, lactate values and TWL increased with distance for both genders (p<0.05). -HR: increased from 100m to 400m (p<0.05). 200m = 300m. -Lactate: increased from 100m to 400m (p<0.05). 200m = 300m. -Velocity: first 50m > other laps (p<0.05)	-The changes in HR, lactate values and TWL increased with race distance. -Velocity in the first lap was higher compared to other laps

Table 2. (Continued)

Study	Race distance	Gender and number of participants	Age (years)	Performance level	Stroke type	Competition type (stage of competition)
Lipinska, Allen, & Hopkins (2016]	800m[2]	Female (n=192)	17-34	Elite	Freestyle	Real competition (heats, semi-finals and finals)

1. Short course (25m pool)
2. Long course (50m pool)

Abbreviation list:
Competitions: World Championship (WC), European Championship (EC), Olympic Games (OG), Pan-pacific championship (PPC), Commonwealth Games (CG), World record (WR).
Measurements: Heartrate (HR), Stroke rate (SR), Rate of Perceived exertion (RPE), Oxygen uptake (VO_2), Blood lactate peak value (La).
Statistical analyses: analyses of variance (ANOVA), coefficient of variation (CV), confidence limits (CL), confidence intervals (CI), the standard error of measurement (SEM).

Methods	Statistical analyses	Pacing profile	Main results	Main findings
Races collected during OG, WC, EC, PPC, Universiades, NC. Measurements: -50m split times -Pacing profiles: linear and quadratic coefficient for the effect of lap number, reductions in time for the first and last laps, and the residual standard error of the estimate.	-Reliability analyses	-Positive	-Mean values of the linear and quadratic coefficients represent a swim with a shallow negative curvature and a slowest lap time in the eleventh lap. -First and last laps were much faster than predicted by the quadratic curve (extremely large and very large reductions in time, respectively).	-The pacing profile described contained a fast initial and final lap. -The middle laps gradually decreased in velocity.

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