Comparison of biomechanical characteristics of freestyle start in period of pre tapering and tapering

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Abstract

Every swimming race begins with the start, and during that phase of the race swimmers are moving with highest velocities. The research consists of videotaping start performances during the period of pre tapering and tapering, analysis of video material and statistical analysis of biomechanical data. Goal of the research was to test the influence of tapering on the starting performance and give answer to the questions if there is significant improvement in 9m time and what is the magnitude of the improvement. Total of 8 swimmers of both genders took a part in the research and 17 biomechanical parameters were tested. Biomechanical data obtained by videotaping was statistically compared to give answers to the questions what biomechanical parameters are changing and what remain unchanged with tapering, what sub phases of the swimming start are changing with tapering and which one can contribute the most for the start improvement. The research has shown significant 9m time improvement calculated as percentage from test 1 to test 2, with mean for improvement of 2,79 ± 1,03%. Although block phase variables showed similar improvement, there was no significant improvement in flight and water phase variables. Coaches and athletes have to focus on all the sub phases of the start because only combination of efficient actions on the block, during the flight, under the water and transitions from one sub phase to another will give the best possible results.

Key words: swimming, swimming start, tapering, biomechanical analysis

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1. Introduction

1.1 Swimming start

Every swimming race begins with the start. Starts for backstroke events are done from the water, but starts for all other swimming techniques, freestyle, breaststroke, butterfly and individual medley are performed from the starting blocks outside of the water (International Swimming Federation [FINA], 2013). Initial speed for the race is produced during the start. To be able to move from the starting block, swimmers need to press their legs against the incline of the starting block and produce the force to propel their body forward. During the start, swimmers travel from the starting block, through the air and dive into the water. The resistance of the water that swimmers are facing during the race is much higher than resistance of the air, which is why swimmers have the greatest speed during the start phase of the race when traveling from the starting block, through the air and into the water.

According to Maglischo (2003), there were many different types of start through the history of swimming sport. As swimming technique was changing and progressing also the swimming start was changing. At the early beginning of swimming as a competitive sport, swimmers were taking positions on the starting blocks with arms extended back and from that position dived forward as seen in Figure 1.

Figure 1. Early swimming start with arms extended behind the back

Later on swimmers and coaches have realized that the start was faster if arms were extended forward and then swung backwards. With that movement swimmers would gain momentum before leaving the block. That starting technique was called direct backward start. Direct backward start was replaced by the Wind-up start where swimmers would, after the initiate still position on the block, move arms in up and backward overhead and then down and forward as the body was leaving the starting block (FINA, 1984; Maglischo, 2003). Modification of this type of start is today in use only for the relay exchanges where it is not required stationary position. From the late 1960's swimmers started using so called grab start (Maglischo, 2003). An advantage of this start over the Wind-Up start is, according to FINA (1984), faster movement off the blocks from required stationary position. The grab start is still in use with some swimmers but in general has been replaced by new starting techniques such as the track start, the handle start and the kick start. In today's competitive swimming the track start is mostly used but with development of new starting blocks with back plate, the kick start is becoming more popular in all competitions where the new starting blocks are available.

During the swimming race, swimmers are not allowed to pull on the lane ropes or walls of the pool or push from them, except start and turn phase when swimmers can push from the block or the wall and on that way gain additional speed (FINA, 2013). Every race except 50 meter events swum in the 50m pool can be divided in 3 phases: start, turn and swimming phase. Of those three phases, starting phase is the shortest in duration, but has a high degree of influence on total race time and final placement. According to Maglischo: "Improving the start can, on average, reduce race times by minimum of 0,10s" (2003, p.265). During the Beijing Olympic Games in 2008, swimmer Milorad Cavic was only 0,01s behind Michael Phelps in 100m Butterfly race (swimrankings.net, 2015). The difference in reaction times during the start between those two swimmers was 0.04s. Reaction time of Phelps was 0.71s and reaction time of Cavic was 0.76s (The Beijing Organizing Committee for the Games of the XXIX Olympiad, 2008). With possibly better start performance Cavic could have eventually prevent Phelps from winning 8 Olympic gold medals and becoming the athlete with most gold medals won at the Olympic Games. At the Olympic Games in

London 2012 difference between 2nd and 4th swimmer in final of 50m freestyle was just 0.07s and between 3rd and 4th just 0.02s (London2012.com, 2012). With such a small difference between medalists and 4th placed swimmer, improved starting performance could potentially have a large impact on results, final placement and medal distribution. Additionally, the shorter the event is, starting time has bigger percentage in overall race time. Comparison of start times for the winners of the men freestyle events in comparison with total race time on European Swimming Championships in Debrecen 2012 are shown in table 1. (Omegatiming, Haljand, 2012).

Table 1. Comparison of reaction time, start time and percentage in overall race (Haljand, 2012)

Race	Reaction time (s)	15m start time (s)	Total time (min.s. hundreds of s.)	Percentage of 15m starting time in overall race (%)
50m freestyle	0.72	5.46	0.21.80	25.05
100m freestyle	0.63	5.80	0.48.77	11.89
200m freestyle	0.76	6.14	1.46.27	5.77
400m freestyle	0.84	6.54	3.47.84	2.87
800m freestyle	0.73	6.40	7.49.46	1.36
1500m freestyle	0.76	7.02	14.48.92	0.74

Each swimming start can be divided in main 3 phases: reaction time, air time and water time, as shown in Figure 2. Those main phases of the start can additionally be divided into 6 sub phases. Those sub phases according to Vantorre, Chollet and Seifert (2010a) are:

- Block sub phase or reaction time (Figure 3a)
- Flight sub phase (Figure 3b and 3c)
- Entry sub phase (Figure 4a)
- Glide sub phase (Figure 4b)
- Leg kicking sub phase (Figure 5a and 5b)
- Swimming sub phase (Figure 5c)

Figure 2. a,b,c Reaction times, start positions and water 15m time

Reaction time or block sub phase is the time from the starting signal until swimmers toes leave the starting block (Maglischo, 2003). It begins when swimmers take the still position on the starting block and last until swimmer's toes leave the starting block. Although ability to react fast on a starting signal is mostly inherent, ability to go from the block faster and further can be trained (Counsilman & Councilman, 1994). Additionally, according to Maglischo: "Measurements with several athletes indicate that reaction time can be shortened by 0.03 to 0.06s by concentrating on the starting signal instead of the starting movements" (2003, p.277). Vantorre, Chollet & Seifert (2014) concluded that in order to have the efficient start, swimmers must find the right balance between two distinctive actions: shorter reaction time and less power production and longer reaction time and more power production. Rapid reaction on the start signal must be optimized with high impulse generated on the starting block. This means that swimmers have to find right balance between spending more time on the starting block and generating higher force or spending less time on the block, generating less force but shortening the reaction time Vantorre et al. (2014). Beginning of block sub phase and end of sub phase of the swimming start is presented in Figure 3a and 3b.

Air time or flight sub phase is the time that the swimmer spends in the air; from the moment when swimmer's toes leave the starting block until his hands touch the water surface (Vantorre et al., 2010a). The flight usually takes 0.3s to 0.4s and distance that swimmers travel through the air is 3m to 4m before entering the water (Blanksby, Nicholson and Elliot, 2002). After leaving the starting block, swimmers are moving through the air in parabolic trajectory (Maglischo, 2003). Movement is forward and up in a first part and then forward and down in the second part of the flight phase. Goal of this phase is to travel as far as possible since the drag forces in the air are lower than in the water, and to enter the water with optimal angle and streamlined position to minimize resistance of the water during the submerse (Vantorre et al. 2014). Flight time mostly depends of the swimmer's ability to produce the force and propel the body from the block and takeoff angle - angle of the body when leaving the starting block. Flight phase of the start is shown in Figure 3c.

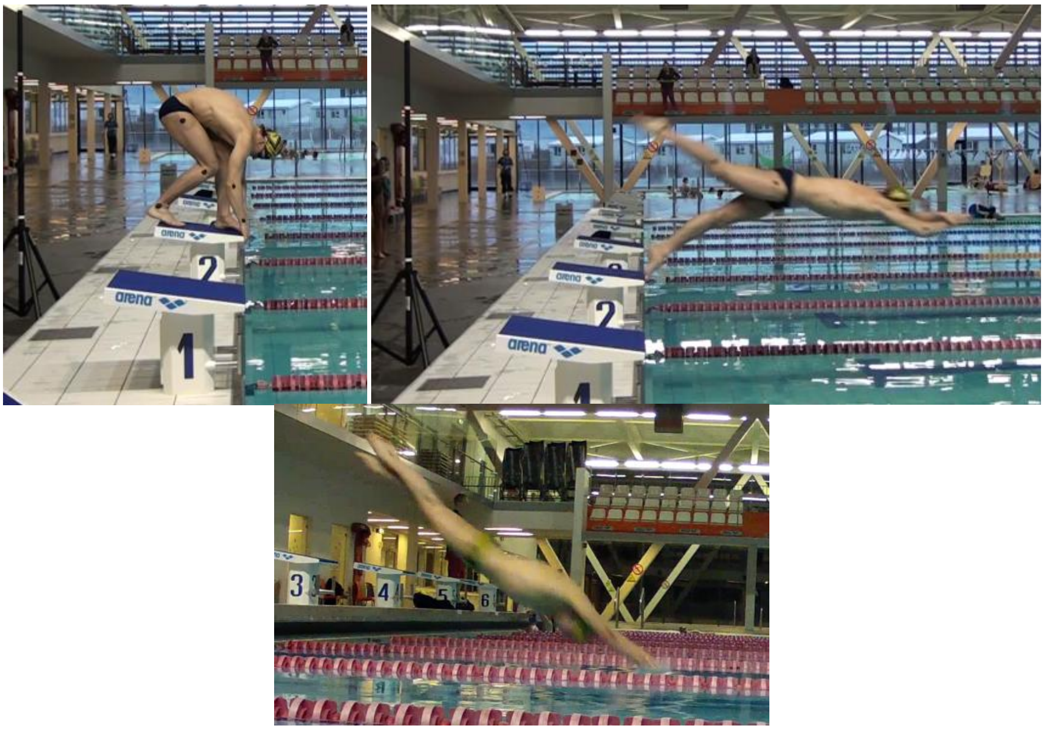


Figure 3a,b,c. Block sub phase, takeoff and flight sub phases of the swimming start

Water time phase is time that swimmers spend from moment when swimmer's hands enter the water until the head touches the 15m mark. This phase is the longest in duration of all three phases of the start and can be trained since there are large differences between swimmers abilities to carry out a well executed under water phase, breakthrough the surface and transition to swimming. Guimaraes and Hay (1985) concluded in their research that around 94% of the variance in start time to 15m was attributed to water phase of the start. The water phase can be improved by minimizing the resistance created by movement of the body through the water and increased propulsion generated by undulating leg movement that is propelling swimmer forward (Sanders & Bonnar, 2008).

Water time phase of the swimming start can be additionally divided into 4 sub phases (Vantorre et al., 2010a). Entry sub phase starts when swimmers hands are entering the water and last until the toes get immersed in the water as shown on Figure 4a. Glide sub phase last from the moment when toes are immerged in the water until legs start with undulating propulsion movements as presented on Figure 4b. Leg kicking sub phase is characterized by undulating propulsion movements of the legs and ends when arms start with propulsion movements as presented on Figures 5a and 5b. Last sub phase of the water phase is swimming sub phase which last from the beginning of the first stroke until swimmer's head arrives to 15m mark. Swimming sub phase of the start are presented on Figure 5c.

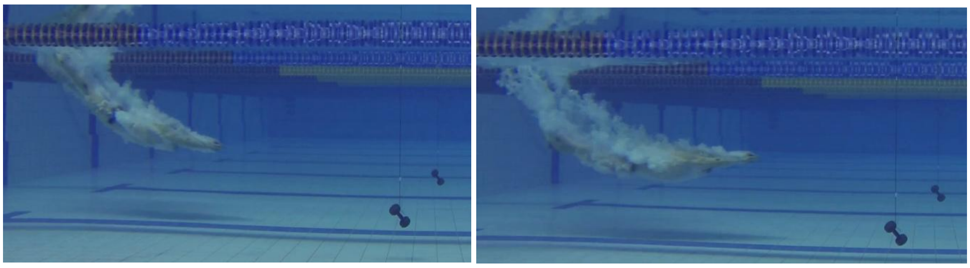


Figure 4a,b. Entry and gliding sub phases of the swimming start

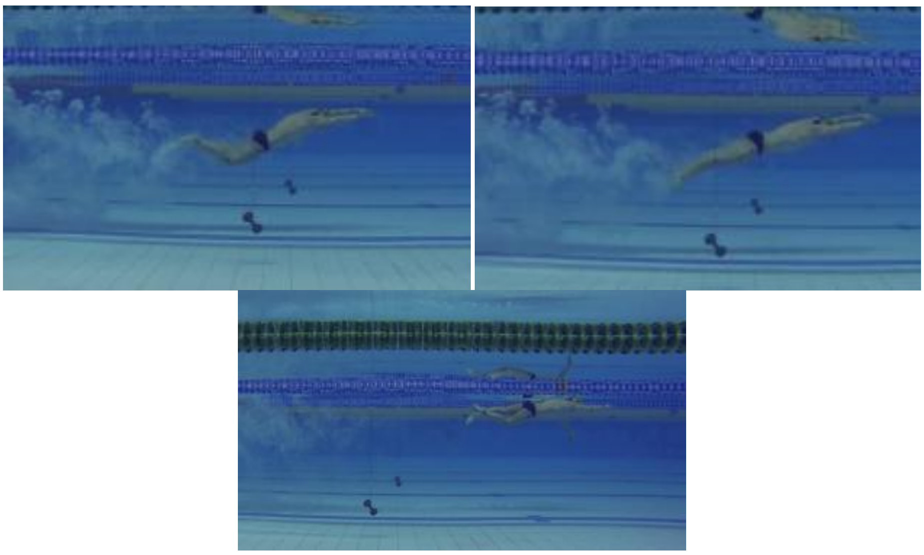


Figure 5a,b,c. The beginning and the end of the kicking sub phase and swimming sub phase of the swimming start

In research conducted by Ruschel, Araujo, Pereira and Roesler (2007) where they carried out kinematical analysis of swimming starts and elements of the start - block time, flight time and water time, they made the following conclusion:

> "An efficient start, in all of the swimming events, depends on the great combination of the actions on the block and the swimmer's projection to the water in order to positively influence the subsequent phases. The flight distance, angle of entry, depth achieved after the water entrance and the velocity performed under the water are all important factors to be observed by athletes and coaches, which should look forward to reach best values of those variables in order to improve the execution of swimming starts"(p.388).

1.2 Drag and propulsion forces during the swimming start

When going from the air into the water, swimmer is facing several difficulties that need to be overcome to be able to maintain the highest possible speed. The density of the water is 1000 kg/m^3 which is around 800 times bigger than density of the air and density of air 1.225 kg/m^3 (Burkett, 2010). So drag or resistance that swimmers are facing in the water is much higher than one of the air. To be able to advance through the air and water, the total sum of propulsive forces must be higher than the sum of drag forces that are working against the swimmer.

Drag is related to the square of the swimming velocity when moving through the water, a result that can be obtained from applying Bernoulli's law to the equation F=P*A, where P is the pressure and A is the area. The equation was applied to swimmers in 1920 by Amar on the form

$$F_d = K v^2$$

where F_d represents drag forces, K is a proportionality constant and v represent the velocity of the swimmer in m/s (Toussaint & Beek, 1992; Toussaint, 2002).
In its most general format the equation becomes (Barbosa, Marinho, Costa and Silva, 2011):

$$F_d = 1/2 C_D \rho A v^2$$

In this equation F_d represents the drag forces, C_D represents drag coefficient, ρ is the fluid density, A is the projection surface of the swimmer and v is swimming velocity relative to the water. This means that drag depends on body position or projection surface of the swimmer but increase of the velocity of the swimmer will drastically increase the drag force that swimmer is facing. Since swimmers are traveling with highest velocities immediately after the start, it means that they will face the highest drag in that phase of the swimming race.

When moving through the water swimmers are facing hydrodynamic resistance or drag which can be divided in two types of the resistance: passive drag and active drag (Vorontsov & Rumyantsev, 2000). Passive drag is experienced by swimmers while gliding. This type of drag will affect swimmer during the gliding phase of the start. By changing the entry angle and holding a streamlined position during the gliding phase of the start, swimmers can influence this passive drag component. Active drag is experienced by swimmers while swimming. Both of those drags that are restricting swimmers movement forward have few components. First is resistance of the air to parts of the body that are moving above the surface. This component is quite small and contributes very little to total drag during the swimming but during the aerial phase of the swimming start, swimmers are facing it (Vorontsov & Rumyantsev, 2000).

Next component of the drag is the friction drag. When moving through the fluid, air or water on the surface of the body is formed boundary layer of fluid. This layer that is in direct contact with the body is sticking to the surface of the swimmer and travels the same speed as the swimmer. Due to viscosity of the water this boundary layer is interacting with next layer of the water and drags it along with but with slightly slower velocity and so on. The more water swimmer carries with while swimming, the greater the friction drag is. Size and smoothness of the body surface, material and tightness of the swimming suit all affect this drag (Vornotsov & Rumyantsev, 2000). Swimmers practice of shaving body parts before important races might contribute in reduction of this form of drag.

Third component is pressure drag that includes two types of drag: form drag and wave making drag. The form drag is result of different pressure created in front and behind the swimmer or by formation of the vortices in the swimmer body's wake and behind it's segments and is produced by the shape and size of the swimmer. In front of the swimmer is area of the high pressure and behind the athlete in the wake is area of the turbulence or the low pressure. This imbalance of the pressures from front to back is opposing the swimmers movement forward and is called the form drag (Burkett, 2010). Since this type of drag depends on the shape and size of the swimmers body, it is extremely important that swimmers who want to swim fast maintain the maximal streamline shape during the water phase of the swimming start (Vornotsov & Rumyantsev, 2000). If any of the body parts like hands, elbows, head etc. are not in alignment, which will increase the form drag and decrease the velocity of the swimmer thus increase the final time of the swimming race. Wave drag is the next type of the drag that is affecting swimmer. This type of drag is formed at the interface where air and water meets. As the swimmer is moving through the water, waves pile up in front and create high pressure area of water that constrict the forward movement of the swimmer (Burkett, 2010). When swimmer is moving on the surface or on a small depth under the surface this type of drag will form. When swimmer is increasing the speed, wave drag is proportional to the cube of velocity, and form drag proportional the square of the velocity (Vornotsov & Rumyantsev, 2000; Burkett, 2010). This means if swimmer doubles the velocity of swimming, the form drag will increase 4 times but wave drag will increase 8 times. According to Vornotsov and Rumyantsev (2000):

> "A characteristic feature of waves generated by a swimmer's body is that they travel at the same speed as the swimmer and their crest-to-crest length is equal to the distance covered by the swimmer per second. As swimming velocity increases, the crest-to-crest wavelength increases until the swimmer's waterline length is the same as the crest-to-crest length of his wave pattern – hull speed. At that velocity the swimmer is trapped in a self-created hole between crests of waves. The more effort that is applied, the deeper the hole and any further attempts to increase swimming speed simply make it impossible for the swimmer to 'climb out of the hole'" (p.190).

It can be concluded from this that taller athletes will have advantage over shorter because they would be able to swim with higher velocities on the surface before reaching the hull speed.

According to Barbosa et al. (2011), frictional drag is the smallest component of the total drag. This drag is decreasing in higher velocities. During the underwater gliding phase it represents around 25% of the drag. Form drag and wave drag present the majority of the drag that swimmers are facing while moving through the water. Both of those drags are increasing with velocity. Wave drag is forming when swimmers are swimming on the surface or near it but there is a significant reduction in this type of drag when swimmers are moving underwater during the start phase of the race. There is no significant wave drag when swimmers are moving at least 0,6m under the surface.

Initial velocity during the swimming start is created when swimmers are applying a force on the start block to jump from the start block into the air. Additionally during the underwater leg kicking phase propulsion is generated by underwater undulatory swimming and propulsion from the kicking and pulling during the swimming phase of the start. According to Vornotsov and Rumyantsev (2000): “Sport practice shows that swimming underwater using kick only is at least no slower than swimming on the surface using the full stroke“ (p.192). According to the same authors the leg actions may be able to create greater hydrodynamic forces than arm actions because of greater propulsive surface, absence of backward movements of the feet during the working part and muscles groups involved in movement that are significantly stronger than the arms.

During the leg kicking phase of the swimming start, the body is extended horizontally with the arms and upper body stationary and legs perform undulatory movements. Characteristics of this leg movements are that during the upbeat and downbeat movement of the legs counter rotating vortices are produced. Those counter rotating vortices are producing a jet stream that is moving swimmer forward (Arellano et al., 2006). Arellano et al. (2002) were using the bubble injection method to visualize the water movements around the feet to observe how the wake is generated. According to them:

> “The water started to rotate during the downward kick reaching the maximum volume of the water in rotation when the upward kick was just starting. This vortex was rotating in a counter-clockwise direction. After finishing the upward kick while the knee attains maximum knee flexion another small vortex is

created, the water was rotating in clockwise direction. Less efficient swimmers did not create this vortex" (p.10).

Those mechanics of propulsion are important to be understood and exploited by swimmers to be able to produce maximal velocities during the starting phase of the swimming race. In modern competitive swimming most of the top performers are using benefits of longer underwater undulatory swimming both to increase propulsion and to decrease wave drag and thus increase velocity and decrease final time of the race.

1.3 Swimming start techniques

There are four main types of swimming starts in today's elite swimming, and few more variations of those four types described in science literature. Blanksby et al. (2002) were comparing grab, track and handle swimming starts so as Sanders and Bonar (2008) and kick start is described by Honda, Sinclair, Mason and Pease (2010, 2012), Nomura, Takeda and Takagi (2010), Slawson et al. (2011). Most of the differences between those starting techniques are in the swimmer's position on the starting block and angle of the body during the take off. The most used swimming starts are grab start, track start handle start and the newest kick start.

1.3.1 Grab start

The grab start was introduced in the late 1960's and shortly became very popular among the swimmers (Maglischo, 2003). In the grab start swimmers stand on the front part of the starting block with feet parallel and shoulder wide. Swimmers grip the front edge with their toes which increase stability on the block and reduce the possibility of slipping during the start. The swimmer is bent down, with knees flexed approximately 30°-40° and hands placed between legs with slightly flexed elbows. This position on the starting block is moving center of mass close to the front edge of the block or slightly in front, to enable faster movement (Maglischo, 2003). One of the best performers of this start was Alexander Popov from Russia, multiple Olympic champion and former world record holder on 50 and 100m freestyle. Alexander Popov performing a grab start is presented in Figure 6.

Figure 6. Alexander Popov performing the grab start

1.3.2 Track start

The characteristic of track start starting technique is that one leg is positioned forward on the starting block with toes grabbing the front edge, while other leg is behind and pressing against the incline of the start block (Maglischo, 2003). The space between the legs should be one to one and a half foot (Quick & Hawke, 2008). Hands are positioned outside of legs and elbows slightly flexed. Center of mass in track start is moved slightly backwards, but differently in two modifications of the track start.

Welcher, Hinrichs and George (2008) carried out research of two modifications of the track start. In the first modification, the sling start or rear weighted track start, swimmer's body is positioned slightly backward and after the starting signal, swimmer would initiate the movement by arm pull so arms would go backwards first and then extend forwards during the flight phase. In the flight phase, the legs would be extended so the body would be in the position with lowest possible resistance. One of the best performers of this modification of track start is Roland Schoeman from South Africa (Figure 7a), multiple Olympic medalist. In the second modification called front weight track start, swimmer's body is positioned more forward on the block and after the starting signal the arms are extended straight forward. One of the best performers of this type of start is Michael Phelps from USA multiple Olympic Champion. The flight phase and water phase are the same in both modifications. Front weight track start is presented on Figure 7b.

Figure 7a,b. Rear weight start performed by Roland Schoeman and front weight start

1.3.3 Handle start

Development of starting blocks with handles on the side enabled swimmers to use them for faster and stronger movement from the block. Handle start is only possible on the starting blocks equipped with side handles (Figure 8a). Swimmer is in the same position like during the grab start, but instead of setting hands between the feet, swimmer is holding to a side handles and using them to hold the body in forward position on the block and initiate the movement from the block. Center of the mass during the handle start is moved far forward and in front of the starting block which is shortening the reaction time (Blanksby et al. 2002). Starting block and flight phase after the handle start are presented in Figure 8a and 8b.

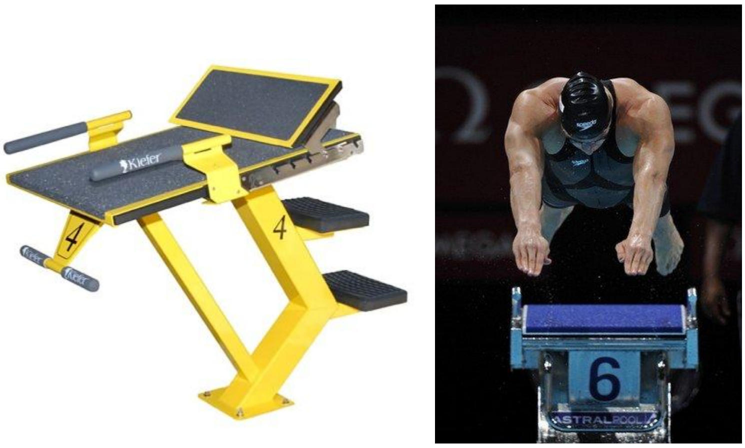


Figure 8a,b. Handle starting block and swimmer in flight phase after performing the handle start

1.3.4 Kick start

In 2009 the World Swimming Federation (FINA) approved a use of the new starting blocks, called Omega OSB11. These starting blocks have the movable kick plate on the rare side of the starting block. Plate is angled at 30 deg to the surface of the block and can be moved through five different positions. Kick start from the starting block OSB11 is modified track start with rear leg positioned on a kick plate. Although relatively new, this start is performed on all major swimming competitions from 2009 including the London 2012 Olympic Games.

Researches were carried out to determine the optimum way to use the advantages of the new starting blocks and a kick start. Properly setting of the rear kick plate would enable swimmers to further produce higher force on the block and to achieve higher takeoff velocities. Position of the rear plate when rear knee angle is between 80° and 90° gives the maximum vertical force but the peak horizontal force is produced when angle is between 100° and 110° (Slawson et al. 2012). Another conclusion is if the stance of the legs is narrower, block time was shorter, peak force on rear plate and horizontal velocity are higher (Slawson et al. 2011). When looking at the swimmer's body position on the block, neutral and slightly backward position on preferred position of back plate would have advantage over front body position (Honda et al. 2012). This is most likely because with the back plate and elevation of the rear part of the start block, center of the mass is moving more forward (Nomura et al. 2010). The largest problem with this start is that most of the swimming pools in the world do not have OSB11 swimming blocks, making it difficult for swimmers to practice it. OSB11 starting block and kick start are presented in Figure 9a and 9b.

Figure 9. OSB11 starting block and swimmer performing the kick start

1.4 Season planning and tapering for peak performance in swimming

In modern sports including swimming, the training process of athletes is divided in a couple of periods with different duration and different priorities in intensity and volume which have the goal to ensure that athletes will peak in their performance at the right time (Dick, 2007). The whole athlete's development is planned through 6 stages of Long Term Athletes Development Plans (LTAD) developed by Balyi (2001) as presented in figure 10. Five stages of LTAD equate to the 5 stages of growth and development: FUNdamentals – childhood; Learn to train - Swim Skills – late childhood; training to train – adolescence; training to compete – early adulthood; training to win – adulthood; first stage Active start is not associated with sport but general motor development (ASA, 2010).

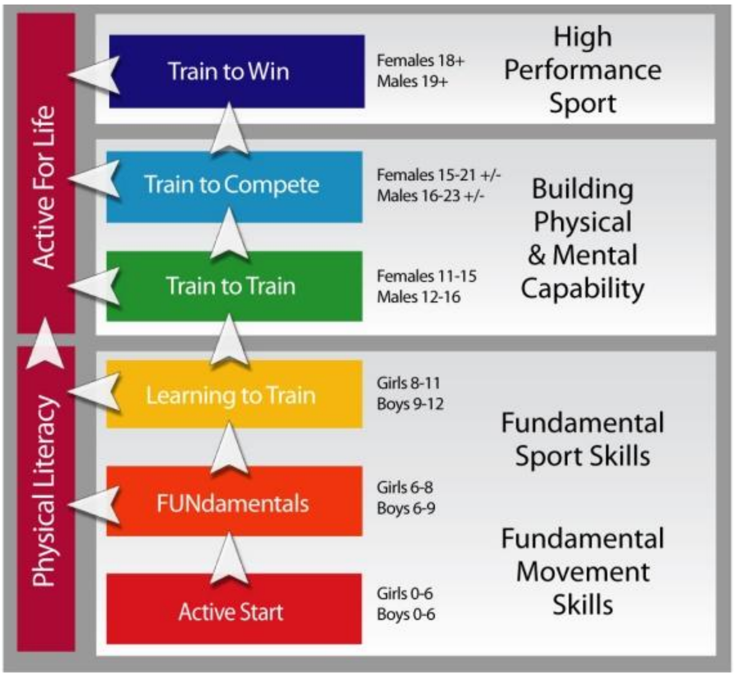


Figure 10. Stages of LTAD

According to ASA, Amateur Swimming Association, English national governing body for aquatic sports (2010):

> „Long Term Athlete Developent (LTAD) is about achieving optimal training, competition and recovery throughout an athlete's career, particularly in relation to the important growth and development years of young people. It provides a

framework within which all sport should plan their training and competition programs“(p.4).

LTAD model adapted for swimming is presented in figure 11.

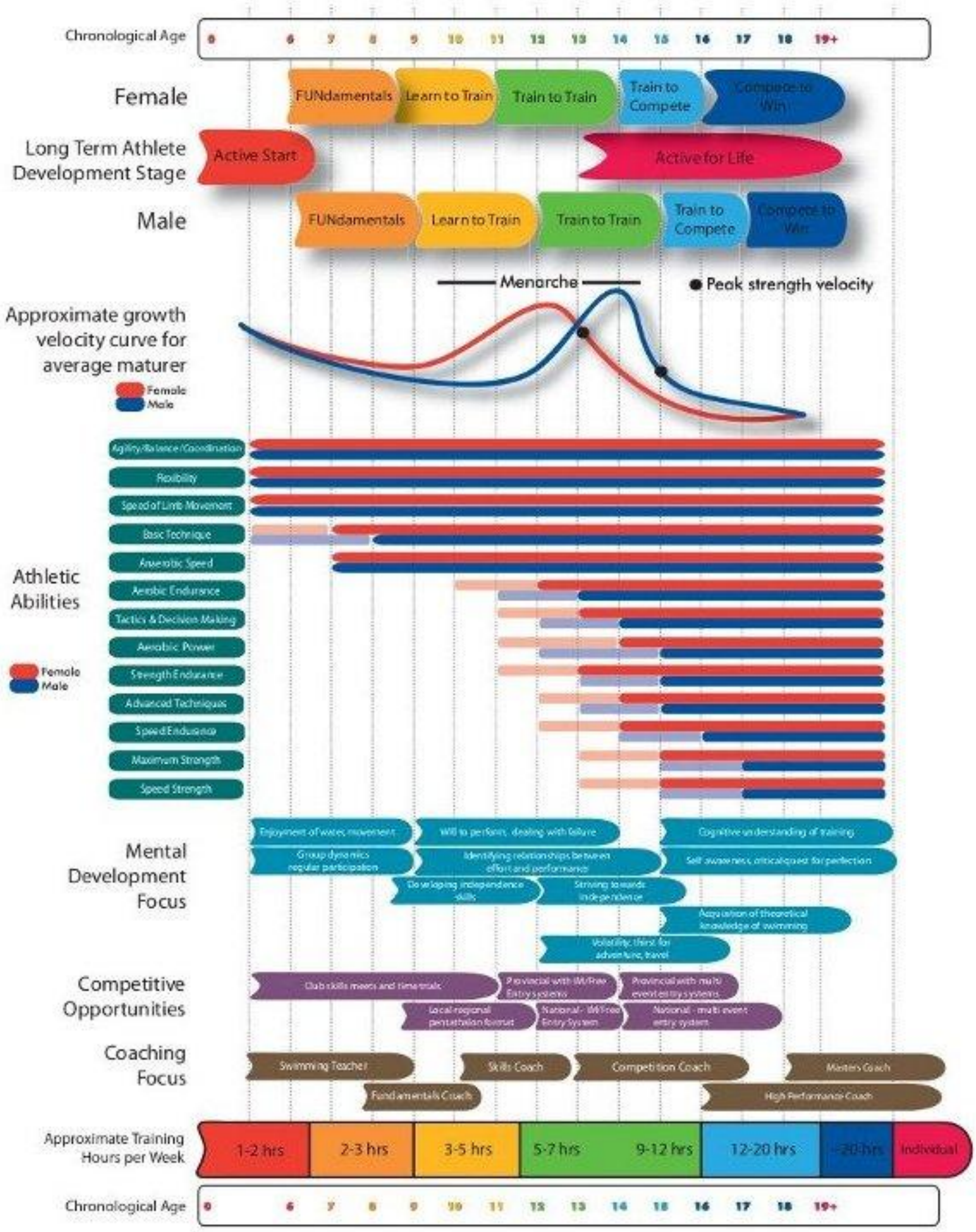


Figure 11. LTAD model for swimming

Additionally the longest training periods in swimming are considered 4 year or Olympic training period and 2 year World Championships training periods. These multiyear periods aim to maximize athlete’s performance on Olympic Games that are held every 4 years or World Championships that are every 2 years.

Using this planning as a guide or framework, next step is yearly planning. Most of the time one year is divided into 2 swimming seasons, period of short course competitions (in 25m pools) and period of long course competitions (in 50m pools). In traditional type of periodization, athletes are progressing through several cycles with specific goals and different duration (Kenney, Wilmore & Costill, 2012). At beginning most athletes are going through preparatory cycle divided in general and specific phase. After that, pre competition cycle is phase of increased volume and intensity followed by tapering period and competition cycle. Finally transition phase helps athletes to recovery from the season and prepare for the next one (Reuter, 2012). Figure 12 shows the traditional model of season plan with one peak.

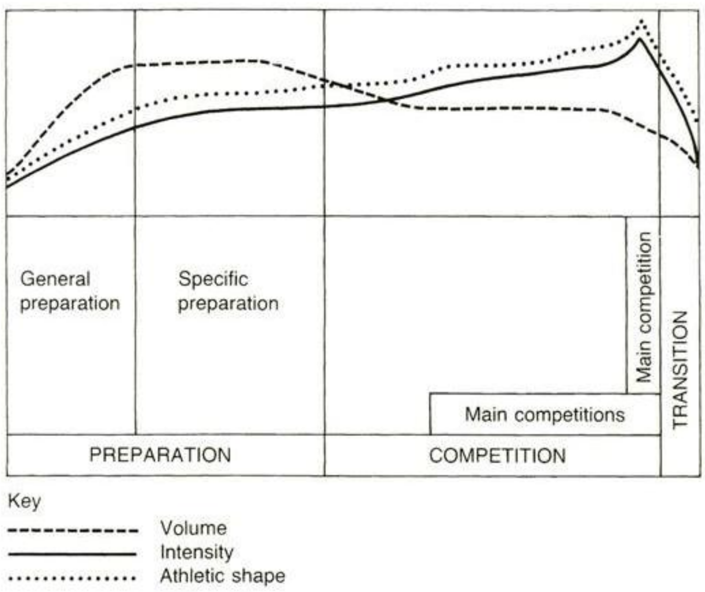


Figure 12. Traditional model of periodization with one peak after Ozolin (1971)

According to Mujika and Pine (2003):

"The taper is a progressive nonlinear reduction of the training load during a variable period of time, in an attempt to reduce the physiological and psychological stress of daily training and optimize sports performance" (p.1182).

Tapering is a specific phase of the athlete's season that usually takes from 4 to 28 days or more (Kenney et al., 2012). To be able to achieve top performance, athletes need to be on maximum of tolerance for physical and psychological stress. Long periods of hard and intense training can have a negative influence on muscular strength and also on mental strength of the athlete which can affect performance in goal competition. To avoid this negative impact of hard training, coaches and athletes are reducing the volume and intensity of the training in variable period before the big competitions to rest and recover the body and mind of the athletes and prepare them for the peak performance. Mujika and Pine (2003) concluded that the goal of the taper is to minimize fatigue which is accumulated during the long training season but without compromising achieved training adaptations. According to the same authors: "Tapering is best achieved by maintaining training intensity, reducing the training volume (up to 60–90%) and slightly reducing training frequency (no more than 20%)". During the tapering, body of the athletes is healing from the damage and stress caused by long period of intensive trainings, and at the same time, energy reserves of the body are replenishing to maximum (Kenney et al., 2012). But tapering is not only rest and recovery. Muscle strength and power are drastically increased during the tapering which is shown in research of Trinity, Pahnke, Reese and Coyle (2006): "Maximal arm power measured using inertial load ergometry increased largely during the first and third weeks after training volume was tapered for peak performance in elite collegiate swimmers (p. 1643)". Many coaches and athletes specially inexperienced ones are avoiding longer tapering periods in fear of decrease in conditioning and decrease of performance on desired competition. But contrary to this, researches has shown that swimmers who reduce the training volumes up to 60% of normal season training volumes during the 15 to 21 days period will not lose any VO_{2max} or endurance performance, blood lactate concentrations after standard test in tapering were lower than in period of normal training and swimmers performed up to 3% faster after tapering period (Kenney et al. 2012). This is in agreement with findings of Maglischo that claims increased performance in swimming by 2 to 4% after period of tapering (2003).

It is important that tapering for peak performance has to be planned by coaches for every individual athlete, because team tapering will not be as much successful as individual (Sweetenham & Atkinson, 2003). Duration of tapering depends on couple of things like gender, swimmers type of specialization (sprint or endurance), muscle mass, the length and type of the swimming competition, swimmer's history, length of the previous swimming season and age of the swimmer (Hanulla, 2003). All those factors need to be considered when planning a tapering for the swimmers.

1.5 Research Questions

The goal of this research is to give an answer to the following questions. First question is to determine if start performance is really faster after the tapering then in period of pre tapering and if possible determine the magnitude of improvement. Second question is to compare the data recorded in the research and see whether there is a significant difference in biomechanical characteristics of the swimming start in pre tapering and tapering period and if yes, where the difference is. Third question is what sub phases of the swimming start are changing the most and had the greatest potential of improvement and thus should be emphasized in trainings during the tapering.

The null hypothesis of the research is:

- H_0 = there is no significant difference in the swimming start performance between period of pre tapering and tapering where swimming start performance consider 9m time from the block.

The working hypothesis is then opposite to null hypothesis:

- H_1 = there is significant difference in the swimming start performance between period of pre tapering and tapering where swimming start performance consider 9m time from the block.

1.6 Importance of the research – possible benefits

We think that our research can be a useful for swimmers and coaches. It could provide data about what elements of the start can be changed and trained specially during the tapering phase of the season to increase the performance. Additionally we are aiming to give an answer to the question what biomechanical characteristics of the start will contribute the most to the swimming performance of the start and potentially can contribute to faster swimming. We think that special benefits will have swimmers that are participating in the research and their coaches because they will have direct data about quality of their start that can be compared within participating swimmers

2. Methods

2.1 Population participants

The research included 9 swimmers, 5 male and 4 female of national level, qualified for The National Championship from the local team that voluntarily took part in the tests. Tests are conducted in the swimming pool with permission of team director. 12 swimmers, 6 male and 6 female, were planned to be included in research but 3 of them, 2 male and 1 female, had to be excluded due to inability to participate in both tests. All swimmers had at least 7 trainings per week in the water, they were swimming similar programs in period of pre tapering and were doing the same length of tapering but individually designed. Tapering was conducted through 2,5 weeks prior to goal competition the National Championship.

Since some of the participants of the research were younger than 18 years old, permission for the videotaping is obtained from their parents prior to research and example of it is presented in appendix. Swimmers older than 18 year old in the moment of testing signed permission that they agree to participate in the research and they agree to be videotaped. Example of that permission is also presented in appendix 1.

2.2 Protocol for testing

The research consists of 2 videotaping of the swimmers performing the track swimming start, analysis of video material, statistical analysis of data taken from video material and making conclusions based on statistical data. The first videotaping is conducted on 18th of October 2014 when swimmers were in period of pre tapering. Second videotaping is conducted 4 weeks later, on 17th of November 2014 a day after participants were taking part in the goal competition, The National Championship, and after 2,5 weeks of tapering and 4 days of racing.

Before each videotaping weight and height of the swimmers was measured and data was used for calculation of resultant force produced at the end of the take off phase of the start. Participants were performing 3 starts with 5min break between each trial. This was done to secure that swimmers will not be fatigued during the starts. Swimmers were starting every 30 seconds in pre determined order and in the same order in both videotaping sessions. Videotaping was done in the afternoon hours following the same individual warm up routine that swimmers were choosing for themselves.

Markers were set on participants prior to swimming start performance. Round markers of 3cm in diameter were painted on following anatomical landmarks as shown on Figure 13: Ulnar Styloid Process, Lateral Epicondile of Humerus, Greater Trochanter of Femur, Head of Fibula and Lateral Malleolus.

Figure 13. Swimmer in starting position with markers set on selected anatomical landmarks

2.3 Equipment

Videotaping was performed with 4 video cameras, one Sony HDR-CX305E with recording speed of 50fps and 3 GoPro3 cameras with 30fps recording speed set outside the water and under the water as shown on Figure 14.

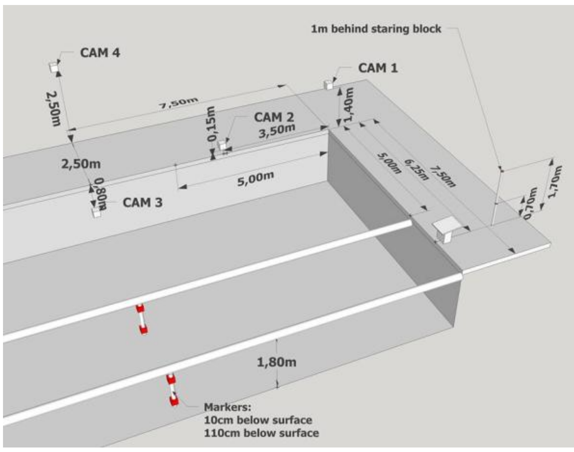


Figure 14. Scheme of cameras and markers set up in the pool

First camera was set lateral of the starting block, 7,5m away and in the height of 1,4m at estimated height level of the swimmer's hips on the block. From this camera, movement time, hip travel distance and takeoff angle data were collected. Second camera was set on the water level and 3,5m away from the wall were starting block is set, and captured the entry angle when arms of the swimmer were touching the water surface. Third camera was set under the water on 0,8m depth and 7,5m from the wall were starting block is set, and captured the underwater phase of the start. Duration of kicking phase, length of the kicking phase and number of underwater kicks data were collected from this camera. Fourth camera is set above the surface on 7,5m from the wall, were starting block is set, and on 2,5m height. From this camera flight distance, flight time, water phase distance, water phase time, total length and total time data was collected.

2.4 Video material analysis

Video material was analyzed by Dartfish 7.0 program for motion analysis. To be able to calibrate Dartfish for accurate analysis, 3 markers of 1m in length on 3 positions were set as presented in Figure 14. The first marker was set behind the starting block at 6,25m away from the camera 1. Second marker was set below the water surface and attached to the lane 5m away from camera 3 and 7,5m away from the wall with starting block. Third marker was set the same as the second marker just attached on lane 7,5m away from the camera 3. Both markers 2 and 3 had weight attached on far end to hold them in place under the water. Those two markers were used to calibrate the Dartfish for the 1m length in level of the swimmer.

2.5 Statistical data analysis

All statistical data were collected, analyzed and presented in IBM SPSS 20.0 program for statistical analysis. In statistical analysis were compared means for selected data variables of each swimmer between first and second trial. Additionally, paired t-test was selected to compare means of selected data variables for the whole group of swimmers. Paired samples t-tests are used when comparisons are made between two measurements of the same population, often pre intervention test and post intervention test (Elvers, 2014). Paired samples t-test are testing null hypothesis that there is no difference between means of two measurements of the same population. Paired t-test can determine if there is significant difference between means of data in first and second trial. By using this test it can be statistically concluded if there is improvement between trials. Level of significance used in paired t-test is 95%, so if the p value is lower or equal than 0,05 there is significant difference between means of variables and the null hypothesis can be rejected (Newell, Aitchison and Grant, 2010).

2.6 Control competitions

Participants of research were taking part in 2 competitions during the research period. The first competition was held on 24th of October 2014, 7 days after the first videotaping while swimmers were still in period of pre tapering. The second goal competition, the National Championship, was held 3 weeks later on 14th of November after the period of tapering. Results achieved by the swimmers on the competitions are recorded. Percentage of improvement is calculated and quality of the results is evaluated by FINA 2014 point tables and compared for two competitions. FINA point calculator was obtained at web site: http://www.manswim.org.nz/calculators/fina_point_calculator.html

Formula for calculating FINA Points are given by FINA (2011):

> "The points are calculated using a cubic curve. With the swim time (T) and the base time (B) in seconds the points (P) are calculated with the following formula:
>
> $$P = 1000 * (B / T)^3$$
>
> The exact formula is used to calculate points from times. Then all point values are truncated to the integer number. Base times for 1000 points are defined for all common individual events and relays, separated for men / women and long course / short course. The base times are defined every year, based on the latest World Record that was approved by FINA. For short course (SCM) the base times are defined with the cut of date of August 31st. For long course (LCM) the base times are defined at the end of the year (December 31st)".

2.7 Data collection

Height and weight of the swimmers was measured before each trial with the same scale. Data was collected from video material using Dartfish 7.0 motion analysis program and includes following kinematical parameters:

Block parameters are presented on Figures 15a and 15b:

- Movement time (Figure 15a): time from the swimmer's first movement on the starting block until toes leave the block
- Hip travel (Figure 15a): distance from point A to B, where A represent marker on the hip before the movement on the starting block and B represent marker on the hip in moment when swimmer's toes are leaving the starting block
- Force: Calculated Resultant force in moment when swimmer's toes are leaving the starting block
- Takeoff angle (Figure 15b): angle between line of the block and line that goes from the hip marker through the point where toes are touching the starting block

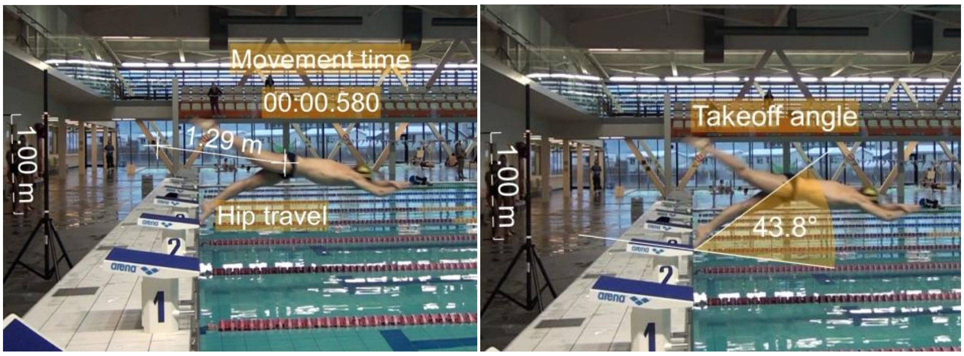


Figure 15a,b. Block parameters

Flight parameters are presented in figure 16 a and b:

- Duration of flight (Figure 16a): time from the take off point until swimmer's fingers touch the surface of the water
- Flight distance (Figure 16a): distance from the starting block to the point where swimmer's fingers touch the surface of the water

- Entry angle (Figure 16b): angle between water surface and line that connects swimmer's fingers, and hip in moment when fingers touch the surface of the water

Figure 16a,b. Flight parameters

Underwater parameters are presented in Figure 17:

- Underwater phase duration: Calculated time from the point when swimmer touch the surface of the water after the flight phase, until swimmer's head breaks the surface of the water (total time – flight time – block time = underwater phase duration)
- Number of underwater kicks (Figure 17): measured number of butterfly kicks performed under the water before head of the swimmers breaks the surface of the water
- Length of the kicking phase (Figure 17): distance between point A and B where A represent the heel of the swimmer's leg on peak of the first kick and B heel of the same leg on peak of the last kick in underwater kicking
- Duration of kicking phase (Figure 17): time from the start of the kicking phase when heel of the swimmer's leg is on the peak of the first kick until the end of the kicking phase when heel of the swimmer's leg is on the peak of the last kick
- Distance per kick: calculated average distance between two highest positions of the heel trajectory
- Frequency of the kicks: calculated number of kicks performed in 1s

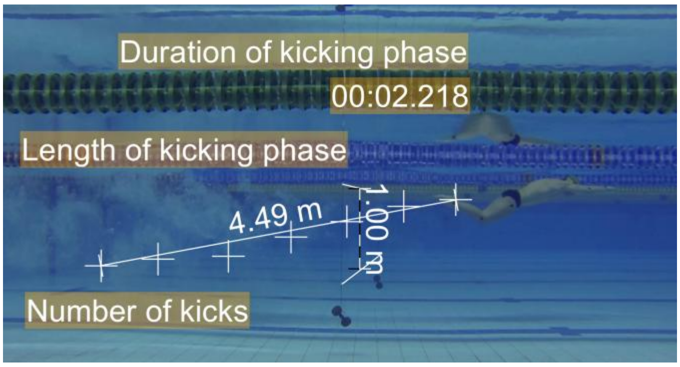


Figure 17. Underwater parameters

Overall start parameters are presented on Figures 18a and 18b:

- 9m time (Figure 18a): measured time when head of the swimmer was crossing 9m mark
- Total length (Figure 18b): length between starting block to the point where swimmer's head is breaking the surface of the water following underwater phase
- Total time (Figure 18b): sum of the block time, flight time and water time. Time from the first movement of the swimmer on the starting block until head breaks the surface of the water following underwater phase
- Average velocity during a breakout: calculated velocity of the swimmer in point when head is breaking up the surface of the water

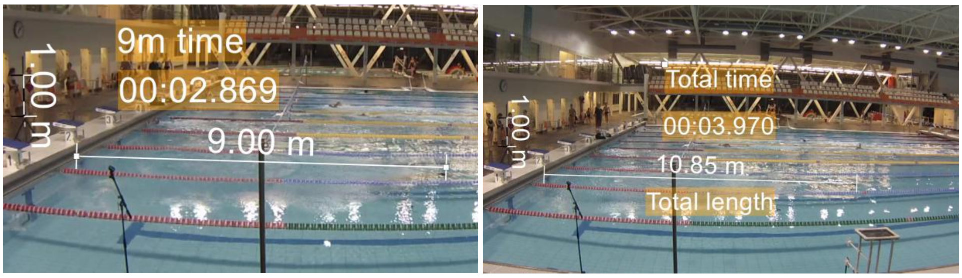


Figure 18a,b. Overall start parameters

3. Results

3.1 Participants

Total of N = 8 swimmers (4 male and 4 female) out of 12 swimmers that volunteered to take a part in the research are included in data analysis, 3 swimmers are excluded prior to the tests due to inability to participate in both tests. Additionally 1 swimmer was excluded even though he finished both tests because he got food poisoning few days before the second test and lost 3kg of body mass which affected his performance. Mean, standard deviation and p value for age, height, weight and quality of the results achieved in control and goal competitions are presented in table 2.

Table 2. Means, standard deviations and p-values for main descriptive characteristics of the tested swimmers for test 1 and test 2

	Mean (SD) Test 1	Mean (SD) Test 2	p value
Age (years)	18,44 (1,55)	18,54 (1,55)	0,749
Height (m)	1,767 (0,068)	1,770 (0,070)	0,104
Weight (kg)	71,7 (3,13)	71,5 (3,02)	0,603
FINA points 2014 average	543 (83)	575 (80)	0,001*

* $p \leq 0,05$

Table 2 shows significant difference $p \leq 0,05$ between two tests only for quality of the result achieved on control competitions expressed with FINA Points 2014. There was no significant difference in age because there was only 4 weeks between tests. Also there was no significant difference in weight and height of participants measured immediately before the tests.

3.2 Competitions

The differences between results of the control and goal competitions, calculated as percentage of improvement, for each swimmer are presented in appendix. Distribution of time improvements between two competitions calculated as percentage is presented in Figure 19.

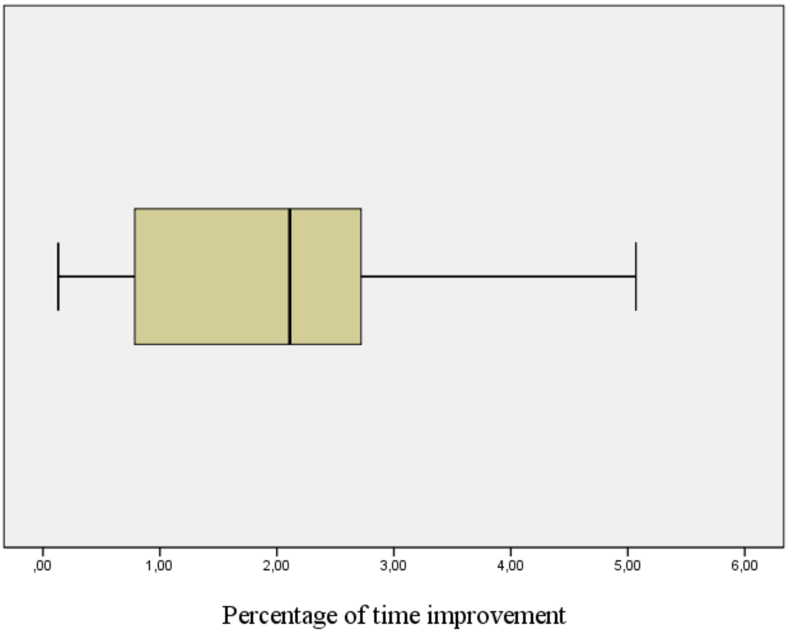


Figure 19. Distribution of time improvement between two competitions in percentages

Mean for time improvement between two control competitions expressed by percentages is 2,00 ± 1,50% with minimum improvement of 0,13% and maximum improvement of 5,07%. Total of 12 results are included in analysis for 8 swimmers. Those are only results for the events that swimmers were taking part in both competitions. All other results are excluded because they couldn't be compared. In 11 out of 12 races participants were swimming faster on goal competition then on control competition. One result where swimmer was swimming slower is excluded from analysis because he was late for the competition so he couldn't do a proper warm up before the race.

3.3 Comparison of kinematical data obtained by the tests in the periods of pre tapering and after the tapering

In the table 3 is presented comparison of means, standard deviations and p values of kinematical variables obtained in period of pre tapering and tapering for the whole group of swimmers.

Table 3. Means, standard deviations and p values of kinematical data obtained in period of pre tapering and tapering

Biomechanical Variables	Mean 1 (SD)	Mean 2 (SD)	p value
Hip travel (m)	1,08 (0,09)	1,12 (0,09)	0,009*
Movement time (s)	0,58 (0,04)	0,57 (0,04)	0,021*
Force (N)	241,71 (72,98)	255,02 (72,97)	0,008*
Takeoff angle (°)	45,37 (9,74)	45,65 (10,64)	0,641
Flight distance (m)	2,84 (0,26)	2,82 (0,25)	0,258
Duration of flight (s)	0,30 (0,07)	0,30 (0,07)	0,685
Entry angle (°)	39,04 (3,93)	40,75 (4,65)	0,007*
Underwater phase duration (s)	3,96 (0,64)	3,98 (0,61)	0,887
Number of kicks (#)	7,04 (1,68)	6,79 (1,90)	0,451
Length of the kicking sub phase (m)	4,56 (1,15)	4,15 (0,88)	0,167
Duration of the kicking sub phase (s)	2,62 (0,73)	2,54 (0,72)	0,609
Distance per kick (m)	0,66 (0,13)	0,62 (0,10)	0,027*
Frequency of the kicks (#/s)	2,74 (0,33)	2,70 (0,29)	0,467
Total length (m)	10,51 (1,04)	10,67 (0,84)	0,280
Total time (s)	4,84 (0,71)	4,85 (0,67)	0,924
9m time (s)	3,56 (0,41)	3,46 (0,39)	0,000*
Average velocity during breakout (m/s)	2,13 (0,22)	2,21 (0,21)	0,004*

* $p \leq 0,05$

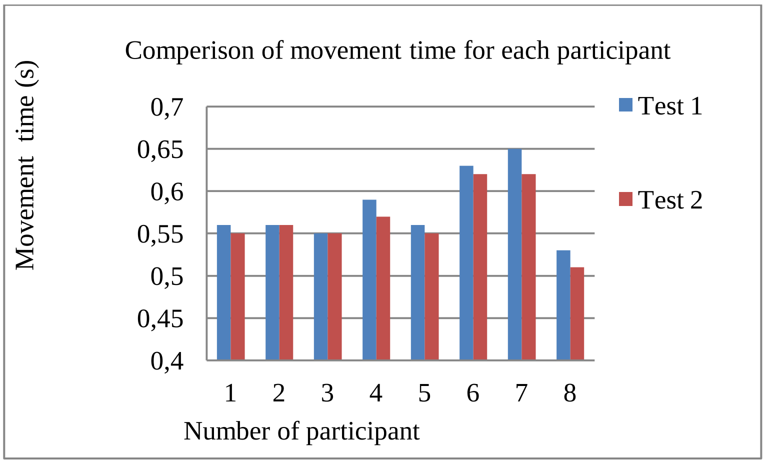
Table 3 shows statistically significant difference ($p \leq 0,05$) for the following variables: Hip travel, Movement time, Force, Entry angle, Distance per kick, 9m time and Breakout velocity. For all other variables: Takeoff angle, Flight distance, Duration of flight, Underwater phase duration, Number of kicks, Length of the kicking sub phase, Duration of the kicking sub phase, Frequency of the kicks, Total length and Total time, there was statistically no significant difference ($p > 0,05$).

Additional comparison of means for selected kinematical data for each participant in period of pre tapering and tapering is presented in the results.

Variables are grouped together in 4 groups of data: block, flight, underwater and total data. Comparison of all kinematical data is presented in appendix.

3.3.1 Block data

Block data include following variables: hip travel, movement time, resultant force during the takeoff and takeoff angle. Three variables which mean showed significant differences between tests are presented in Figures 20a and 20b and Figure 21. Figures 20a and 20b present comparison of hip travel and block time between 2 tests for each participant. Figure 21 present comparison of resultant force during the takeoff for each participant. Test 1 represents the measurements in pre tapering period and test 2 represents the measurements after the tapering period.



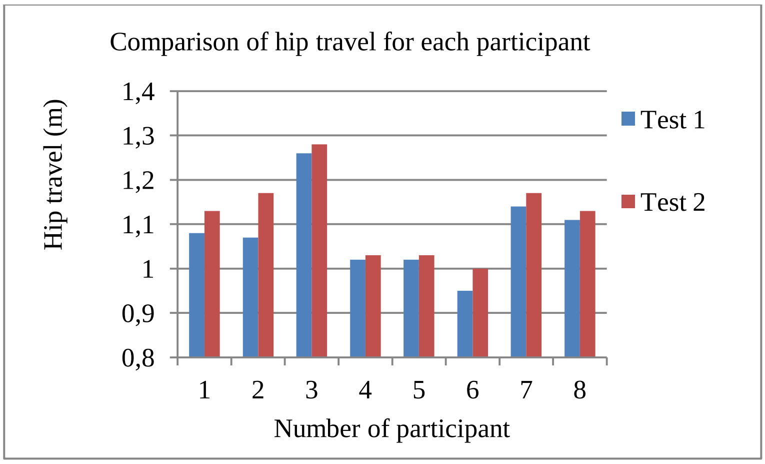


Figure 20a,b. Comparison of movement time and hip travel between test 1 and test 2 for each participant

It is clear from Figure 15 that all participants had the same or quicker block time in second test and all participants had longer distance that hip was traveling from still position until the moment when swimmer's toes were leaving the block.

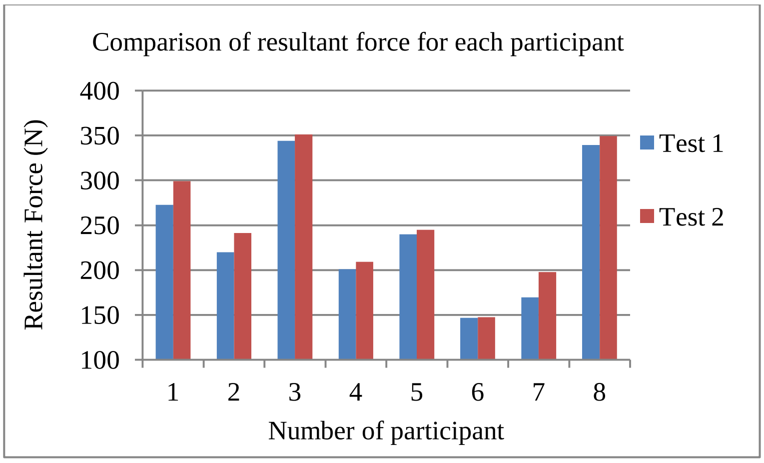


Figure 21. Comparison of resultant force between test 1 and test 2 for each participant

From the Figure 21 it can be seen that all participants had greater resultant force production during the takeoff in the second test.

3.3.2 Flight data

Flight data include following variables: flight distance, flight time and entry angle. Of those three variables only mean of entry angle variable showed significant difference between test 1 and test 2. Comparison of entry angle between 2 tests for each participant is presented in Figure 22.

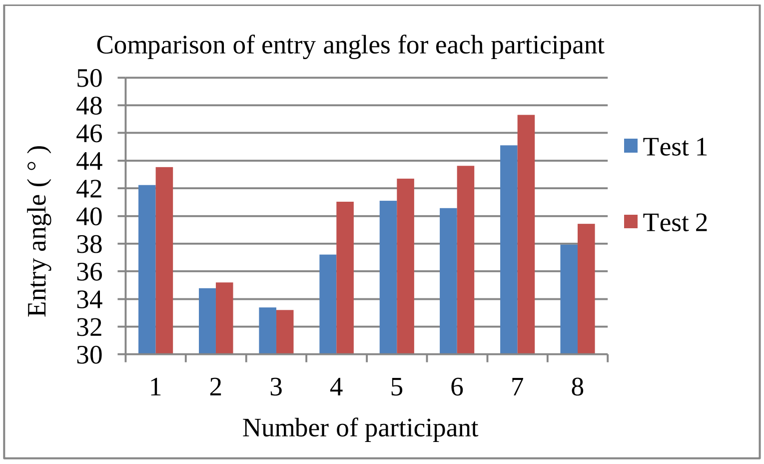


Figure 22. Comparison of entry angles between test 1 and test 2 for each participant

From the figure 22 it can be seen that 7 out of 8 participants had higher entry angle on test 2 in comparison with test 1.

3.3.3 Underwater data

Underwater data include following variables: underwater phase duration, number of kicks, duration of the kicking sub phase, length of the kicking sub phase, frequency of the kicks and distance per kick. Of those 6 variables only distance per kick variable showed significant difference between test 1 and test 2. Comparison of means between test 1 and test 2 for each participant is presented in Figure 23.

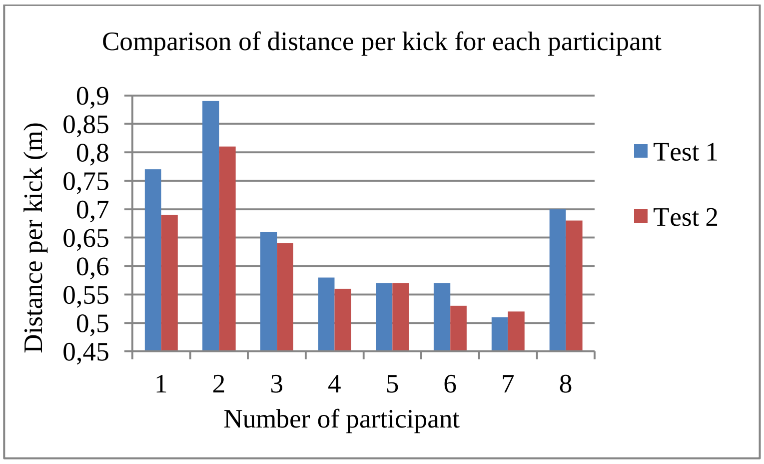
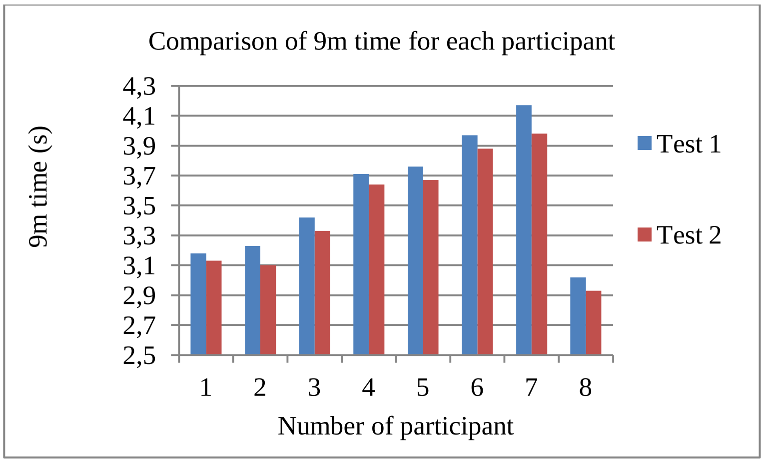


Figure 23. Comparison of distance per kick variable between test 1 and test 2 for each participant

On the figure 23 it can be seen that only 1 swimmer had greater distance per kick in the second test. Remaining 6 swimmers had shorter distance and 1 swimmer didn’t show any change between two tests in distance per kick.

3.3.4 Total start data

Total start data include following variables: total length, total time, 9m time and relative breakout velocity. Of those 4 variables, 9m time and relative breakout velocity showed significant difference between two tests. Comparison of means between test 1 and test 2 for those two variables for each participant are presented in figure 24a and 24b.



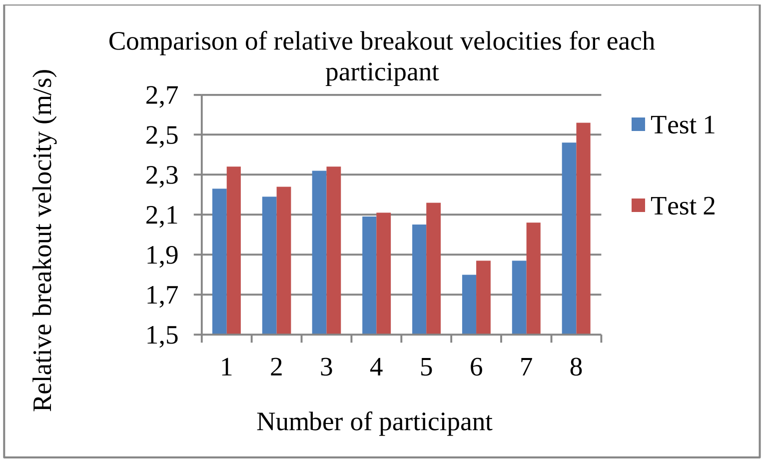


Figure 24a,b. Comparison of 9m time and relative breakout velocities between test1 and test 2 for each participant

From the figure 24a and 24b can be seen that all participants had shorter 9m time in the second test when compared to first one and also higher calculated relative breakout velocity.

If improvement of 9m time from test 1 to test 2 is calculated as percentage of the result, then mean for improvement of 9m time is 2,79 ± 1,03% of result achieved in test 1 with minimum achieved improvement of 1,57% and maximum achieved improvement of 4,56% as presented in figure 25a. Improvement of 9m result calculated as percentage for each participant is presented in figure 25b.

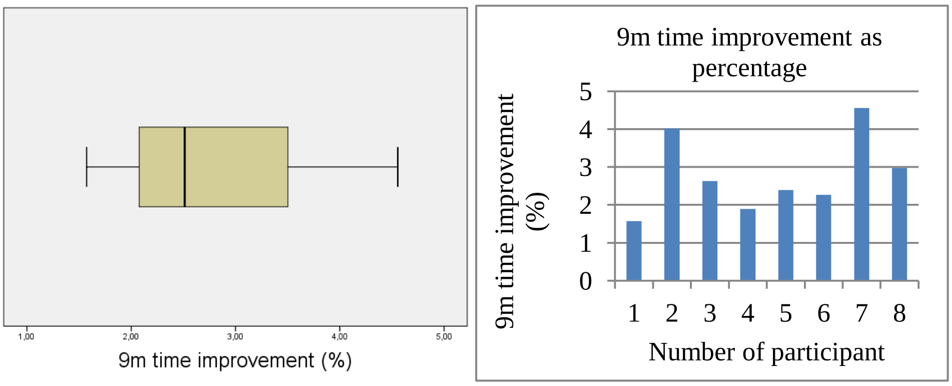


Figure 25a,b. Distribution of 9m time improvements calculated as percentages and presented for each participant

3.3.5 Phases of the start as percentages of start duration

Calculated percentages of movement time, flight time and underwater time in total time of the start for each individual and for the test 1 and test 2 are presented in Figure 26 and Figure 27. The mean values, standard deviations and p values of selected start phases times calculated as percentages of the total start time are presented in the table 4.

Table 4. Means, standard deviations and p values of selected start sub phases durations calculated as percentages of total start duration obtained in period of pre tapering and tapering

Phase of the start	Mean (SD) Test 1	Mean (SD) Test 2	p value
Movement time (%)	**12,20 (1,40)**	**11,78 (1,08)**	**0,163**
Flight time (%)	**6,29 (1,30)**	**6,32 (1,46)**	**0,860**
Underwater time (%)	**81,53 (1,81)**	**81,90 (1,77)**	**0,445**

From the table 4 it can be concluded that there is no significant difference ($p \leq 0,05$) for duration of the selected start sub phases when calculated as percentages of total start duration.

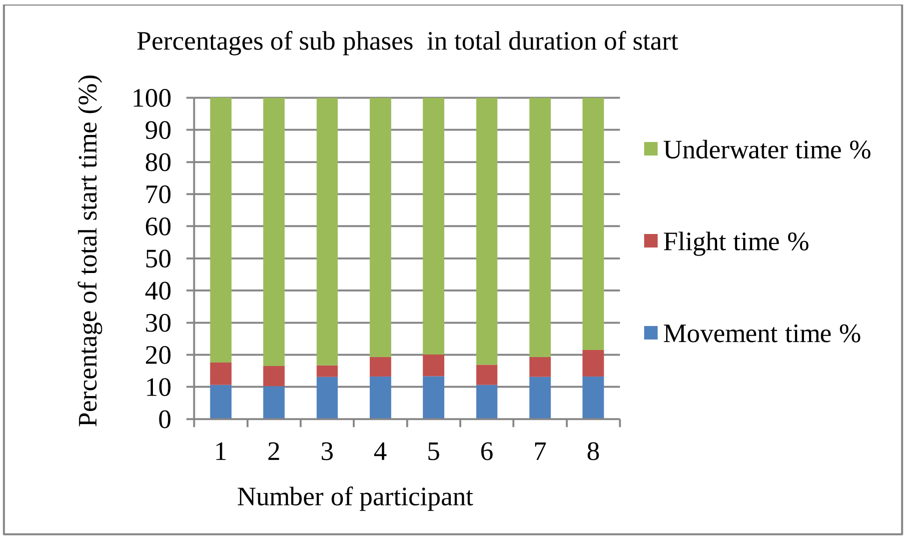


Figure 26. Selected start sub phases duration as percentages of total start duration test 1

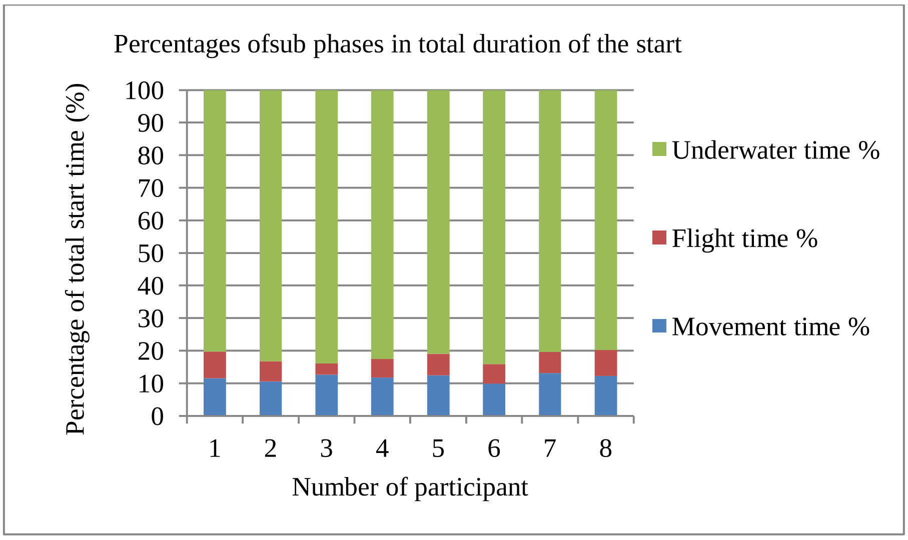


Figure 27. Selected start sub phases duration as percentages of total start duration test 2

4. Discussion

The 3 main goals of the research were:

- To determine if the starting performance is faster in period of tapering then in pre tapering period
- What biomechanical parameters were changing during the tapering period and what remained unchanged
- If the change exist in swimming performance, how are the sub phases of the start changing and which sub phase will contribute the most to increased swimming performance

4.1 Effects of tapering on start performance

To give an answer to the first research question if starting performance is faster after tapering, it is necessary to explain the choice of 9m time as the referent value for improvement of start performance. Previous studies of swimming starts included different lengths, from 5m to 15m, as a referent values. Welcher et al. (2008) used 5m mark, Blanksby et al. (2002) used 10m mark and Vantorre et al. (2010b), Seifert et al. (2010) used 15m mark time as a referent value. Since the goal of the research was to analyze only block, flight and underwater phases of the start but not swimming up to 15m, 9m mark was selected as a distance which all participants covered while still kicking underwater.

From the data obtained by comparison of results achieved in control and goal competition it is quite clear that for selected population of swimmers tapering for the goal competition was successful. Calculated improvement of results between control and goal competition have mean of 2,00 ± 1,50%. Considering only start and conducted tests, mean of improvement of 9m time between test 1 and test 2 is 2,79 ± 1,03%. If means are analyzed and compared for relative breakout velocities between test 1 and test 2, improvement of relative breakout velocity in percentages between test 1 and test 2 is 3,94 ± 2,72%. And this gives answer to our first research question that performance of swimming start for selected population was indeed faster after tapering then in period of pre tapering. The obtained results of the research are in accordance with data from Maglischo (2003) who stated that swimmers can perform faster after tapering from 2% to

4%. Other researchers concluded that tapering can enable faster performance up to 3% according to Mujika and Padila (2003) and Kenney et al. (2012). Although participants in the tests were relatively young with mean age 18,44 ± 1,55 and on national competitive level, they achieved similar improvement in competition results, 9m test times and relative breakout velocities as international level swimmers observed by Mujika, Padilla and Pyne (2002). They were analyzing 99 performances of male and female swimmers during the Sydney 2000 Olympic Games and achieved mean improvement of 2,18 ± 1,50% from control competition 3 weeks prior, with minimum achievement value of -1,14% and maximum value of 6,02%.

With presented results in mind, we can reject the H_0 – null hypothesis of research that there is no significant difference in the swimming start performance between period of pre tapering and tapering where swimming start performance consider 9m time from the block.

4.2 Effects of tapering on biomechanical and kinematical variables

To give an answer to the second question, what biomechanical parameters were changing during the tapering period and what remained unchanged, each of the phases of the start will be analyzed separately and kinematical data will be discussed.

4.2.1 Block data

Block variables: movement time, hip movement and resultant force during the takeoff showed significant difference between two tests but there was no significant difference for the takeoff angle variable. Difference in hip travel between 2 test have mean of 3,4 ± 2,89%, all 8 participants achieved longer hip travel distances in test 2 in comparison with test 1. Difference in movement time between 2 tests have mean of 2,12 ± 1,69% and 6 out of 8 participants had shorter block time and 2 participants show no change between test 1 and test 2. Difference in resultant force during the takeoff showed mean of 5,93 ± 5,50% with all participant improving force production from test 1 to test 2 but with different magnitude. Maximum improvement for this variable was 16,50% and minimum 0,50%. Difference in percentages for the takeoff angles between two tests have mean of 0,14 ± 4,47% where 3 swimmers showed decrease and 5 swimmers had increase in takeoff angle in test 2. It can be concluded that improvement in block data which has shown significant difference between test 1 and test 2 is showing the similar magnitude of improvement of 2 to 4 % as race improvement or 9m time improvement.

The obtained results for movement time with mean of 0,58 ± 0,04s for the test 1 and 0,57 ± 0,04s are slightly faster than values for the track start presented by Blanksby et al. (2002) of 0,64 ± 0,07s. In analysis of takeoff angles, obtained mean values for test 1 (45,37 ± 9,74°) and test 2 (45,65 ± 10,64°) are slightly higher than values of other researchers. Seifert et al. (2010) obtained measured values of takeoff angle for track start of 27,6 ± 7,7°. Benjaventura, Edmunds & Blanksby (2007) were testing the elite and recreational swimmers and concluded that elite swimmers had much lower takeoff angles than recreational swimmers for the grab start (27,45 ± 5,99° versus 39,62 ± 13,19°). Since our tested population with mean results of 575 ± 80 FINA2014 points is far away from elite level of 90% of world record or around 900 FINA points (Vantorre et al. 2014), values obtained in test 1 and test 2 for the takeoff angle are also pointing that swimmers are closer to recreational swimmers rather than elite in comparison with values of Benjaventura et al. (2007).

4.2.2 Flight data

Flight variables: flight distance and flight time did not show any significant difference between test 1 and test 2. Significant difference was found only for the entry angle variable. Although, it was expected that increase of the resultant force production during the takeoff would cause the increase in flight distance and duration of the flight that was not the case for the selected population. Obviously swimmers were not able to apply higher force efficient enough to produce longer length and longer duration of the flight similar to results of research obtained by Breed and Young (2003).

Data obtained in the research for duration of flight (0,30 ± 0,07s) for both tests is very similar to data from Vantorre et al. (2010b) which measured 0,31 ± 0,07s, Galbraith, Scurr, Hencken, Wood & Graham-Smith (2008) which measured

0.30 ± 0.08s and Blanksby et al. (2002) which measured 0,30 ± 0,04s and slightly less than results of Thanpoulos et al. (2012) which tested young Greek swimmers and obtained results of 0,41 ± 0,07s for boys and 0,38 ± 0,06s for girls. Flight distance means of test 1 and test 2 (2,84 ± 0,26m, 2,82 ± 0,25m) are slightly lower than distances of 3,01 ± 0,35m obtained by Blitvich, McElroy, Blanksby, Clothier & Pearson (2000) but similar to results of Blanksby et al. (2000) which measured 2,73 ± 1,25m.

Entry angle is the only flight variable that showed significant difference between test 1 and test 2 (39,04 ± 3,93° and 40,75 ± 4,65°). Only 1 out of 8 swimmers had smaller entry angle in test 2. Values of entry angles are between values measured by Thanopoulos et al. (2012) of 43,85 ± 4,48° for males and 44,79 ± 4,00° for females, Blitvich et al. (2000) of 42 ± 7° and Seifert et al. (2010) of 37,1 ± 3,8°. Obviously with increase of the entry angle, swimmers were aiming to achieve entry with less splash and thus reduce front resistance. It could be speculated also that increase of the resultant force during the takeoff and increase of the takeoff angle caused increase in the entry angle since 5 out of 7 swimmers which had increase in the takeoff angle had also increase in the entry angle but didn’t show significant difference in flight length.

4.2.3 Underwater data

Out of 6 variables analyzed for underwater phase of the start only distance per kick variable showed significant difference between test 1 and test 2. From the obtained data it is clear that swimmers in the research showed inconsistency and great variability in number of underwater kicks and also variables that are connected to that like length and duration of the kicking sub phase and duration of underwater phase, frequency of the underwater kicking and distance per kick.

Results obtained by research for underwater phase duration for test 1 and test 2 (3,96 ± 0,64s and 3,98 ± 0,61s) are similar to results of Vantorre et al. (2010b) of 3,43 ± 0,92s for elite swimmers but different from training swimmers 2,13 ± 0,72s. Duration of kicking phase for test 1 and test 2 (2,62 ± 0,73s and 2,54 ± 0,72s) are also similar to results of Vantorre et al. (2010b) of 2,55 ± 0,90s for elite swimmers but different from training swimmers 1,57 ± 0,69s. Frequency of the kicks for test 1 and test 2 (2,74 ± 0,33Hz and 2,70 ± 0,29Hz) are similar to results of Houel, Elipot, André & Hellard (2013) that measured 2,32 ± 0,22Hz and higher then results of 2,17 ± 0,32Hz obtained by Gavilán, Arellano & Sanders (2009). In research of Arellano et al. (2002) obtained frequencies for international level swimmers were 2,14Hz and for national level swimmers 1,76Hz.

4.3 Effects of tapering on the sub phases of the swimming start

From the table 5 we can conclude that there was no significant difference in relative duration of the 3 phases of the start. From Figures 26 and 27, we can conclude how much each of the selected sub phases of the start contributes to the total time. Movement time represent around 12% of the total time, flight time represent around 6% and underwater time has a value around 82% of the total time for the selected population of the swimmers. However absolute durations of the movement time and 9m time are showing significant difference. From the obtained results it is easy to conclude that underwater phase and leg kicking sub phase have the biggest potential for improvement and contribute the most to the efficiency of the swimming start since they are longest in duration similar to conclusion of Guimares and Hay (1985) that underwater phase contributed 94% of the difference in start performance to 15m. Calculated percentages or relative duration might be different than other researchers like Vantorre et al (2010b) who were taking into consideration also reaction time beside movement time on the block and swimming time up to 15m, but absolute durations of the phases analyzed in this research are very similar.

4.4 Limitations and benefits of the research

One of the major problems that researchers were facing in the research is a low number of the participants. As previously stated, planned number of participants 12 had to be reduced to 9 that entered research and finally 8 participants were included in results. The reason why more swimmers were not included in the research is that swimmers from other swimming groups or swimming teams, that were available for the research, were doing tapering of different durations which could influence the results of the research.

Another limitation of the research was the videotaping. In use were 2 types of cameras. First camera had speed of 50fps but other three cameras had speed of

30 fps which resulted in a temporal discrepancy of the measurements from frame duration of 0,02s to frame duration of 0,033s. Additionally, force plate could be used for measurement of the force production during the takeoff which could give more precise results and also both horizontal and vertical force could be measured.

Another thing that could be included in research is analysis of other sub phases of the start like entry phase, gliding phase and swimming up to 15m phase. Additionally, reaction time could be included together with movement time to obtain block time. Inclusion of those sub phases should be part of the future researches to complete the research of influence of tapering on start performance.

One of the major benefits of the research is the obtained knowledge about importance of efficient start performance and necessity of increased practice of the starts during the tapering before the major competitions. Selected population of swimmers had a problem of transferring the increased power generated during the takeoff into the flight phase to produce longer flights. With the knowledge of results and tools to measure the takeoff and entry angles, swimmers could practice starts and be more efficient in first 2 sub phases of the start and thus potentially decrease the starting time and overall time of the race. In comparison of researches on elite and recreational – training swimmers researched by Vantorre et al. (2010b) and Benjaventura et al. (2007) with selected population of this research, it can be concluded that selected swimmers were closer to recreational group when it comes to takeoff angles and closer to elite group when it comes to kicking phase, frequency of the kicks and underwater phase, so takeoff angles is something to focus on in the future.

The results of the research are in accordance with Ruschel et al. (2007) which stated that for efficient execution of the swimming starts coaches and athletes have to focus on all the sub phases of the start because only combination of actions on the block, in the air and under the water, and also transitions from one sub phase to another will give the best possible results. One kinematical variable is not more important than the others and all of them have to be practiced and optimized for the best performance of the start.

5. Conclusion

From the research, following conclusions can be made. Tapering has similar influence on the start performance as on total race performance. The results of 9m time showed improvement of 2,79 ± 1,03% which is similar to achieved race improvement of 2,00 ± 1,5%. Variables of the block phase were showing similar magnitude of improvement as race and 9m times, but that improvement was not efficiently transferred into the flight phase. Water phase, as the longest in duration, has the biggest potential of improvement and thus could contribute the most to the faster start performances. Coaches and swimmers need to pay special attention to start practice during the tapering and to observe, measure and control all the variables of the start to maximize the start performance.

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Appendix 1 - examples of permission of videotaping and using a data in research purpose

Date 15.10.2015

I undersigned swimmer ………………………………………………….
Confirm that I am voluntarily participating in the research with title "Comparison of biomechanical characteristics of freestyle start in period of pre tapering and tapering" conducted by Hermann Páll Traustason and Mladen Tepavcevic as a part of final thesis research in Sport Science studies of Reykjavik University.

I am giving permission to Hermann Páll Traustason and Mladen Tepavcevic to videotape me doing swimming starts and use the data in research purpose.

____

Signature

Date 15.10.2015

I, undersigned parent / legal guardian of the underage swimmer …………………………………………………., confirm that my son / daughter is voluntarily participating in the research with title "Comparison of biomechanical characteristics of freestyle start in period of pre tapering and tapering" conducted by Hermann Páll Traustason and Mladen Tepavcevic as a part of final thesis research in Sport Science studies of Reykjavik University.

I am giving permission to Hermann Páll Traustason and Mladen Tepavcevic to videotape my son / daughter while doing swimming starts and use the data in research purpose.

____

Signature

Appendix 2 – comparison of all kinematical variables for each participant

Table 5. Comparison of block phase variables between 2 measurements for each participant

Number of participant	Hip travel 1 (m)	Hip travel 2 (m)	Block time 1 (s)	Block time 2 (s)	Force 1 (N)	Force 2 (N)	Takeoff angle 1 (°)	Takeoff angle 2 (°)
1	**1,08**	**1,13**	**0,56**	**0,55**	**272,77**	**299,00**	**59,83**	**59,33**
2	**1,07**	**1,17**	**0,56**	**0,56**	**220,00**	**241,33**	**36,93**	**35,73**
3	**1,26**	**1,28**	**0,55**	**0,55**	**344,00**	**351,13**	**29,13**	**26,63**
4	**1,02**	**1,03**	**0,59**	**0,57**	**201,00**	**209,30**	**42,47**	**43,56**
5	**1,02**	**1,03**	**0,56**	**0,55**	**240,03**	**244,80**	**44,93**	**47,73**
6	**0,95**	**1,00**	**0,63**	**0,62**	**146,87**	**147,60**	**54,83**	**56,23**
7	**1,14**	**1,17**	**0,65**	**0,62**	**169,67**	**197,67**	**50,07**	**50,67**
8	**1,11**	**1,13**	**0,53**	**0,51**	**339,40**	**349,30**	**44,77**	**45,33**

Table 6. Comparison of flight phase variables between 2 measurements for each participant

Number of participant	Flight distance 1 (m)	Flight distance 2 (m)	Time of flight 1 (s)	Time of flight 2 (s)	Entry angle 1 (°)	Entry angle 2 (°)
1	**3,07**	**3,08**	**0,37**	**0,39**	**42,23**	**43,53**
2	**3,08**	**3,07**	**0,34**	**0,33**	**34,77**	**35,20**
3	**2,65**	**2,67**	**0,15**	**0,15**	**33,40**	**33,2**
4	**2,73**	**2,70**	**0,27**	**0,28**	**37,20**	**41,03**
5	**2,56**	**2,53**	**0,28**	**0,29**	**41,10**	**42,70**
6	**2,74**	**2,71**	**0,37**	**0,37**	**40,57**	**43,63**
7	**2,60**	**2,61**	**0,31**	**0,31**	**45,10**	**47,30**
8	**3,28**	**3,19**	**0,33**	**0,33**	**37,93**	**39,43**

Table 7a. Comparison of water phase variables between 2 measurements for each participant

Number of participant	Underwater phase duration 1 (s)	Underwater phase duration 2 (s)	Number of kicks 1	Number of kicks 2	Length of kicking sub phase 1 (m)	Length of kicking sub phase 1 (m)
1	**4,36**	**3,84**	**7,67**	**5,67**	**5,93**	**3,92**
2	**4,55**	**4,43**	**6,67**	**6,00**	**5,91**	**4,88**
3	**3,49**	**3,64**	**4,33**	**4,33**	**2,88**	**2,77**
4	**3,60**	**4,01**	**7,00**	**7,67**	**4,05**	**4,28**
5	**3,35**	**3,58**	**6,33**	**6,00**	**3,61**	**3,39**
6	**4,90**	**5,23**	**10,00**	**10,67**	**5,66**	**5,65**
7	**4,29**	**3,80**	**8,33**	**7,67**	**4,23**	**3,99**
8	**3,15**	**3,31**	**6,00**	**6,33**	**4,17**	**4,29**

Table 7b. Comparison of water phase variables between 2 measurements for each participant

Number of participant	Duration of kicking sub phase 1 (s)	Duration of kicking sub phase 1 (s)	Distance per kick 1 (m)	Distance per kick 2 (m)	Frequency 1 (Hz)	Frequency 2 (Hz)
1	**3,25**	**2,18**	**0,77**	**0,69**	**2,36**	**2,60**
2	**3,17**	**2,93**	**0,89**	**0,81**	**2,10**	**2,05**
3	**1,48**	**1,47**	**0,66**	**0,64**	**2,93**	**2,94**
4	**2,51**	**2,87**	**0,58**	**0,56**	**2,79**	**2,67**
5	**2,10**	**2,08**	**0,57**	**0,57**	**3,02**	**2,89**
6	**3,64**	**3,87**	**0,57**	**0,53**	**2,75**	**2,76**
7	**2,81**	**2,66**	**0,51**	**0,52**	**2,96**	**2,88**
8	**2,01**	**2,24**	**0,70**	**0,68**	**2,98**	**2,83**

Table 8. Comparison of total start variables between 2 measurements for each participant

Number of participant	Total length 1 (m)	Total length 2 (m)	Total time 1 (s)	Total time 2 (s)	Relative breakout velocity 1 (m/s)	Relative breakout velocity 2 (m/s)	9m time 1 (s)	9m time 2 (s)
1	**11,77**	**11,18**	**5,28**	**4,77**	**2,23**	**2,34**	**3,18**	**3,13**
2	**11,96**	**11,90**	**5,45**	**5,32**	**2,19**	**2,24**	**3,23**	**3,10**
3	**9,73**	**10,20**	**4,18**	**4,35**	**2,32**	**2,34**	**3,42**	**3,33**
4	**9,77**	**10,25**	**4,46**	**4,86**	**2,09**	**2,11**	**3,71**	**3,64**
5	**9,21**	**9,56**	**4,19**	**4,42**	**2,05**	**2,16**	**3,76**	**3,67**
6	**11,19**	**11,67**	**5,90**	**6,25**	**1,80**	**1,87**	**3,97**	**3,88**
7	**9,77**	**9,96**	**4,97**	**4,73**	**1,87**	**2,06**	**4,17**	**3,98**
8	**10,69**	**10,61**	**4,01**	**4,15**	**2,46**	**2,56**	**3,02**	**2,93**